STATUS OF MINERAL RESOURCE INFORMATION FOR THE FORT APACHE INDIAN RESERVATION, ARIZONA

By

C. T. Wrucke
U. S. Geological Survey

Mark H. Hibpshman
U. S. Bureau of Mines

Administrative Report BIA-77
1981

CONTENTS

SUMMARY AND CONCLUSIONS . . . 1

INTRODUCTION . . . 1
Previous Investigations . . . 2
Physiography . . . 3

GEOLOGY . . . 3
General . . . 3
Rock Units . . . 4
Precambrian Rocks . . . 4
Redmond Formation . . . 5
Ruin Granite . . . 5
Apache Group . . . 5
Troy Quartzite . . . 6
Diabase . . . 6
Mississippian, Devonian, and Cambrian Rocks . . . 6
Pennsylvanian Rocks . . . 7
Permian and Pennsylvanian Rocks . . . 7
Permian Rocks . . . 8
Cretaceous Rocks . . . 8
Tertiary Rocks . . . 8
Sedimentary Deposits . . . 8
Andesite and Basalt . . . 9
Latite . . . 9
Basalt . . . 9
Quaternary Deposits . . . 9
Structure . . . 9

ECONOMIC GEOLOGY . . . 10
Known Mineral Resources . . . 10
Metallic Mineral Resources . . . 11
Iron . . . 11
Manganese . . . 11
Copper . . . 12
Nonmetallic Mineral Resources . . . 12
Asbestos . . . 12
Gypsum . . . 13
Building Stone . . . 13

Construction Materials . . . 13
Mineral Fuels . . . 14
Subbituminous Coal . . . 14
Uranium . . . 14
Potential Mineral Resources . . . 14
Geothermal Energy . . . 14
Oil and Gas . . . 15

MINERAL RESOURCES . . . 15
Fuel Resources . . . 15
Coal . . . 15
Geothermal Resources . . . 16
Petroleum and Natural Gas . . . 16
Uranium . . . 16
Metallic Resources . . . 17
Cobalt . . . 17
Copper . . . 17
Gold . . . 18
Iron . . . 18
Apache Hematite Deposit . . . 19
Chediski Deposit . . . 20
Cow Creek Hematite . . . 21
Marley-Grasshopper Hematite . . . 21
Oak Creek (Grasshopper Ranch) Hematite . . . 21
Split Rock (Gentry-Rock Creek) Hematite . . . 22
Reserves and Mining . . . 22
Manganese . . . 22
Apache Property . . . 23
Accord Deposit . . . 25
Reserves . . . 25
Silver . . . 25
Nonmetallic Resources . . . 26
Asbestos . . . 26
Apache Mine (Crown Asbestos Mines, Inc.) . . . 27
Apache Extension Group . . . 28
Stansbury Deposit . . . 28
White Tail Group (Horse Shoe Nos. 1 and 2, and Enders Nos. 1 and 2) . . . 28
Loey and Lena Prospect . . . 30
Roadside Mine (Cibecue Mining Co., Inc., Old Prochnow Property) . . . 30
Snake Hill Deposit . . . 30

Fiber King Mine (Salt Bank, River Side) 31
Bluff Claims 33
Reserves 34
Gypsum 34
Clay 35
Limestone 35
Salt 36
Sand and Gravel 36
Specialty Sand 37
Scoria (Cinders) 38
Stone 38
Turquoise and Other Decorative Material 38

MAP COVERAGE 39

RECOMMENDATIONS 40

REFERENCES 41

SUMMARY AND CONCLUSIONS

Known mineral resources on the Fort Apache Indian Reservation include coal, iron, manganese, asbestos, gypsum, clay, sand and gravel, and scoria. The reservation also is believed to contain significant quantities of specialty sand, chemical and metallurgical limestone, and several varieties of rock that may be suitable for use as dimension stone and crushed stone. The area also is reported to contain gold in placer deposits, and minor copper occurrences have been reported. The reservation is considered to be prospective for oil and gas, geothermal energy, and uranium. Decorative materials, such as geodes, turquoise, crystalline barite, onyx, and banded gypsum, are present.

Deposits on the reservation have yielded iron, manganese, asbestos, clay, sand and gravel, scoria, and apparently a small amount of salt. Current production is limited to scoria and sand and gravel. A distinct possibility exists for future production of iron and asbestos. The extent and quality of such commodities as specialty sands and clays should be investigated. Coal on the reservation has not been adequately explored; however, an effort should be made to determine the extent and quality of this commodity.

INTRODUCTION

This report was prepared for the Bureau of Indian Affairs (BIA) by the U.S. Geological Survey (USGS) and the Bureau of Mines (USBM) under an agreement to compile and summarize available information on the geology, mineral resources, and potentials for mineral development of certain Indian lands. Source material included published and unpublished reports and personal communications. No fieldwork was done.

The report also includes information supplied by the authors from their personal knowledge of the geology and mineral resources of the reservation and surrounding areas.

The present report makes frequent reference to the detailed paper by Moore (1968) on the mineral deposits of the reservation. Moore's report is a valuable source of information available in the mid-1960s. Since the publication of Moore's work, new reports have appeared on the rock units, structural geology, and mineral resources of Arizona, and advances reported in these papers are emphasized here.

The Fort Apache Indian Reservation includes parts of Apache, Gila, and Navajo Counties in east-central Arizona. The reservation is an irregularly shaped area about twice as long in an east-west direction as in a north-south direction and encompasses 1,664,872 acres (Figure 1). All land on the reservation is tribally owned. According to BIA, the population of the White Mountain Apache Tribe was 7,686 in 1978. All mineral rights on the reservation apparently are owned by the tribe.

The reservation is a mountainous region having spectacular scenery. Timber covers most of the area. The northern border of the reservation is the Mogollon Rim; the southern boundary is marked by the Salt and Black Rivers. The topography is rough with high relief and clear, fast streams. Major drainages are the Salt, Black, and White Rivers. Lesser drainages include Canyon Creek, Carrizo Creek, and Big Bonito Creek. The tribe has designated a wilderness area near the east-central edge of the reservation as the Fort Apache Mt. Baldy Wilderness (Figure 1). This is a tribal designation and is not part of the National Wilderness system. The wilderness area encompasses about 8,500 acres, and is not open to mineral exploration or development.

The major artery through the area is U.S. Highway 60; State highways 77, 73, and 260 afford access to other parts of the reservation, and county and BIA roads allow entry to more remote areas. The Apache Railway Company's southern terminus is at McNary in the northern part of the reservation. The Apache Railroad joins the Atchison Topeka and Santa Fe tracks at Holbrook, Ariz., 72 miles to the north.

Principal towns in the vicinity are Show Low (population 2,285) and Globe (population 7,333); Phoenix (population 581,562) is about 135 miles west of Tribal headquarters at Fort Apache (U.S. Department of Commerce 1970). The main communities on the reservation are Whiteriver (population 5,000) and Fort Apache (population 200-300). Population figures are BIA estimates.

Previous Investigations

Geologic studies of the Fort Apache Indian Reservation began during the Wheeler survey west of the 100th meridian. Marvine (1875)[1] in 1871 and Gilbert (1875) in 1873 traveled across parts of the Colorado Plateau, descended the south slope of the Mogollon Rim, and camped at Fort Apache, then called Camp Apache. Both men conducted reconnaissance examinations of the sedimentary and volcanic rocks and made observations that stand today. Gilbert measured a stratigraphic section, identified the Cretaceous age of the coal-bearing deposits near the Mogollon Rim, and noted that Baldy Peak is an old volcano lacking a crater at the top.

The first review of the geology in relation to mineral deposits of the reservation was by Reagan (1903). Reagan reported older and younger Precambrian rocks in the region, and, in the terminology of the day, correlated the Apache Group with the Precambrian Unkar rocks in the Grand Canyon and identified the Troy as the Tonto Sandstone, thereby implying that it was of Cambrian age. He could not have realized that the age of the Apache Group and the Troy were to be controversial for the next half century. Ransome (1903), working in the Globe area, defined the Apache Group and thought it was Cambrian. Resolution of the controversy began in the 1940s when Shride (1967), who was examining iron and asbestos deposits on the reservation, noted that the diabase that widely intrudes the Apache Group and the Troy Quartzite is deeply weathered below Devonian strata and concluded correctly that all of these rocks are Precambrian.

As an outgrowth of his earlier work, Ransome (1917) reinterpreted a stratigraphic section measured by Gilbert (1875) at the head of Canyon Creek. Two years later Darton began field work that resulted in a geologic map of Arizona and a comprehensive report (Darton, 1925) that included a discussion of the Fort Apache Reservation.

[1]An earlier paper by Endlich cited by Moore (1968) concerns the White River area of Wyoming, not Arizona.

Since the appearance of Darton's paper, the reservation has been the subject of many reports. These include studies of Paleozoic strata by Huddle and Dobrovolny (1952), Winters (1963), and Teichert (1965), of late Precambrian rocks by Shride (1967), of asbestos deposits by Wilson (1928) and Stewart (1955, 1956), of iron deposits by Stewart (1947) and Harrer (1964), and of the mineral deposits in general by Moore (1968). Excellent detailed geologic maps of parts of the reservation have been made by Finnell (1966a, b) and McKay (1972), and a detailed account of the volcanic and Quarternary geology of the Baldy Peak volcano have been presented by Merrill and Pewe (1977). These reports cite additional references on the geology and mineral deposits of the reservation.

Physiography

The Fort Apache Indian Reservation lies mostly in the northern part of the mountain region of central Arizona and includes an adjacent part of the Colorado Plateau. A canyon and upland topography occupies the western two-thirds of the reservation and slopes to the south, away from the steep escarpment of the Mogollon Rim, one of the most prominent physiographic features in Arizona. The Rim defines the southern margin of the Colorado Plateau east along the northern border of the reservation about to the longitude of White River. Streams that begin under the Rim gradually become deeper to the south, and although they locally widen into broad valleys utilized for cultivation, they create a rugged to moderately rugged topography in most areas to the Salt River at the southern border of the reservation. In the vicinity of Highway 60, the Salt has cut a gorge about 2,000 ft deep. North from the Black River, which marks the southern border of the reservation to its confluence with the Salt, the topography rises to the White Mountains, culminating at Baldy Peak, the highest mountain in Arizona outside the San Francisco Peaks, near Flagstaff. As a result of extending from a desert environment at altitudes as low as 2,700 ft in Salt River Canyon to the thickly forested alpine terrane at 11,403 ft on Baldy Peak, the Fort Apache Indian Reservation encompasses a remarkably great variety of Arizona landscapes.

GEOLOGY

General

The rocks of the Fort Apache Indian Reservation consist of Precambrian igneous and metamorphic rocks overlain by subhorizontal Precambrian, Paleozoic, and Mesozoic sedimentary strata, which in turn are locally to extensively capped by gravels and volcanic flows of Tertiary age (see Table 1, Figure 2). The Precambrian rocks crop out along the western and southwestern border of the reservation, whereas the Paleozoic and Mesozoic rocks blanket the western and central parts of the area. Tertiary volcanic rocks cover the eastern third of the reservation and are part of a large volcano centered at Baldy Peak in the White Mountains. The subhorizontal strata broken by few faults indicate that the rocks of the reservation belong to the Colorado Plateau structural province.

TABLE 1

Rock Units of the Fort Apache Indian Reservation

Era	Period	Epoch	Rock Units	Thickness (ft)
Cenozoic	Quaternary		Alluvium and glaciofluvial deposits	0-100+
	Tertiary	Pliocene	Younger basalt	500(?)
		Miocene	Older basalt	400(?)
			Latite	1,600
			Andesite and basalt	200-600+
		Miocene (?) to Eocene (?)	Sedimentary deposits	100-1,200
Mesozoic	Cretaceous		Sedimentary rocks	500
Paleozoic	Permian		Kaibab Formation	0-180
			Coconino Sandstone	200-450
	Pennsylvanian		Supai Formation	1,300
			Naco Formation	800
	Mississippian		Redwall Limestone	25-225
	Devonian		Martin Formation	6-400
	Cambrian		Tapeats Sandstone	0-280
Precambrian			Diabase	
			Troy Quartzite	0-1,000
			Apache Group: Basalt	0-20
			Apache Group: Mescal Limestone	10-350
			Apache Group: Dripping Spring Quartzite	325-650
			Apache Group: Pioneer Shale	100-400(?)
			Ruin Granite	
			Redmond Formation of Livingston	5,000

Rock Units

Precambrian Rocks

A two-fold division of the Precambrian rocks exists throughout southeastern Arizona. In the Fort Apache Indian Reservation, an older sequence of deformed metavolcanic rocks of the Redmond Formation of Livingston (1969) intruded by a large mass of Ruin Granite almost certainly forms the basement beneath all of the reservation. These rocks were deeply eroded, then beveled to a plain of low relief, before the younger sequence, mostly of shallow marine sedimentary deposits of the Apache Group and Troy Quartzite, was laid down. After an episode of faulting and folding, which only locally disrupted the regionally horizontal disposition of these strata, diabase was emplaced as generally tabular, concordant intrusions, mostly in the younger sequence. The stratified rocks of the older sequence are metamorphosed to the green-schist facies of regional metamorphism, whereas the granitic rock and younger strata are unmetamorphosed except for contact metamorphic effects produced during emplacement of the diabase.

Redmond Formation.--The weakly metamorphosed dacite and trachyandesite ash-flow tuffs, volcanic sedimentary rocks, and andesite flows named the Redmond Formation by Livingston (1969) crop out at the southwestern corner of the reservation along and near the northwest bank of the Salt River. The formation lies at the base of a thick sequence of quartzite, argillite, slate, and phyllite exposed at the White Ledges on the southeast side of the river (Livingston, 1969). This sequence, including the Redmond Formation, is probably correlative with the Pinal Schist, which is exposed from Gila County to the southeastern corner of the state. Livingston (1969) dated the formation at 1,510 m.y. using techniques that tend to give young ages for rocks as old as these. A more reasonable age in view of dates obtained from loosely correlative rocks in the Mazatzal Mountains of central Arizona is about 1,715 m.y. (Silver, 1964). Cuffney (1977) studied the part of the formation exposed in the reservation and reported that the greenstone and metadiorite described by Moore (1968) and shown by Wilson and others (1959) as diorite on the geologic map of Gila County are ash flows of the Redmond Formation that aggregate about 5,000 ft in thickness.

Ruin Granite.--The porphyritic quartz monzonite that crops out from the lower part of Canyon Creek (Cuffney, 1977) to the western boundary of the reservation resembles the Ruin Granite, which has been recognized in much of the area around Globe. Livingston (1969) dated the Ruin at 1,425 m.y., whereas Silver (1969) reported that occurrences of Ruin-type granite are 1,430-1,460 m.y. old.

Apache Group.--As redefined by Shride (1967), the Apache Group comprises in ascending order, the Pioneer Shale, the Dripping Spring Quartzite, the Mescal Limestone, and an unnamed basalt. These rock units crop out along the western border of the reservation and in the deep canyon of Salt River to about 5 mi east of Flying V Canyon. They were deposited after emplacement of the 1,450-m.y.-old Ruin Granite on which they accumulated and before diabase intruded them about 1,150 m.y. ago. The rocks of the Apache Group could have accumulated over a considerable span of this time interval.

The Pioneer Shale is composed of the Scanlan Conglomerate, 1 to 8 ft thick, and an overlying section composed of pale-reddish-purple to reddish-brown tuffaceous siltstone or silty mudstone, and very coarse to fine-grained arkosic sandstone 100-400 ft thick in the reservation. Elliptical light-colored spots as much as 1 in. across are common through the fine-grained parts of the formation.

The Dripping Spring Quartzite consists of three members. The basal Barnes Conglomerate member, 5 to 25 ft thick, contains well-rounded pebbles and cobbles of quartzite, white quartz, jasper, and metamorphic rocks in a matrix of arkosic sandstone. The middle member, 140 to about 300 ft thick, is orange to gray, thin- to thick-bedded, commonly crossbedded arkosic sandstone and feldspathic quartzite. The upper member, 180 to nearly 300 ft thick, is dominantly brown to dark gray, thin-bedded feldspathic siltstone, and, where pyritic and carbonaceous, is the host for uranium deposits.

The Mescal Limestone has been subdivided into three members. The lowest member is 150 to 200 ft thick and where not drastically modified by silicification or contact metamorphism consists of thin- to thick-bedded cherty dolomite, commonly with a 0 to 15 ft thick massive brown sandstone at the base. The middle member, 40 to 130 ft thick consists of a distinctive thick-bedded stromatolitic dolomite overlain by thin-bedded cherty dolomite devoid of algal structures. In the vicinity of Canyon Creek north of the 34 Parallel, the carbonate members of the Mescal were drastically thinned by erosion and solution prior to deposition of the Troy Quartzite. An upper argillite member, known in areas to the west and south, is absent in sections exposed on the reservation. Layers of cherty hematite as fillings in solution cavities in the carbonate members and in parts of the upper Canyon Creek area make up a continuous blanket at the top of the formation. Metamorphism resulting from intrusion of diabase has converted most of the dolomite in the formation to limestone (fine-grained marble) containing calcium-magnesium-silicate minerals. Serpentine is pervasively distributed through the limestone, and where locally abundant contains asbestos.

An unnamed basalt crops out locally above the upper member of the Mescal on the reservation. It is a fine-grained to porphyritic flow 0-20 ft thick, and commonly impregnated with hematite.

<u>Troy Quartzite</u>.--Resting unconformably on the Apache Group along the western border of the area and in the canyon of Salt River are quartzite and sandstone of the Troy Quartzite. Shride (1967) subdivided the formation, in ascending order, into the arkose member, the Chediski Sandstone Member, and the quartzite member. The type locality of the Chediski Sandstone Member is at Chediski Butte on Canyon Creek. These members have a maximum aggregate thickness of about 1,000 ft. In places, as near the head of Canyon Creek and east of Highway 60, the Troy is thin or absent as a consequence of erosion before basal Paleozoic strata were deposited.

<u>Diabase</u>.--The youngest of the Precambrian rocks in the reservation is diabase that intruded the Troy Quartzite and older rocks, principally as sills and sheets but locally as dikes. The diabase is greenish black, normally exhibits very fine grained chilled borders 6 to 18 in. thick, and variously is fine to very coarse grained; some sills are everywhere coarse grained farther than about 20 ft from chilled margins. Sills were intruded at preferred stratigraphic horizons in the sedimentary section, and individual sills can be traced for distances as great as several miles at the same stratigraphic position. Some diabase masses are as thick as 700 ft, but commonly the thicker bodies are multiple intrusions consisting of one sheet enclosed within another. The total volume of diabase approximates the volume of the sedimentary host rocks (Shride, 1967). The most widely accepted are of the diabase as obtained from Pb-U and K-Ar methods is 1,150 m.y. (Silver, 1963; Livingston and Damon, 1968).

Mississippian, Devonian, and Cambrian Rocks

Rocks of Mississippian, Devonian, and Cambrian age crop out high on the steep slopes east of Canyon Creek and along Salt River and its tributaries east to the confluence with White River. They include the Tapeats Sandstone of Cambrian age, the Martin Formation of Devonian age, and the Redwall Limestone of Mississippian age. In general, the formations thin to the north in the reservation and have a maximum aggregate thickness of about 800 ft.

The Tapeats Sandstone records the beginning of Paleozoic sedimentation in east-central Arizona. It is composed of clastic sedimentary material that was deposited in channels carved in Precambrian rocks. In central Arizona this sandstone has been considered as Devonian by some authors (Huddle and Dobrovolny, 1952; Teichert, 1965) and Cambrian by others (Finnell, 1966a, b), but now is thought likely to be Cambrian (Elston and Bressler, 1978). It consists mainly of poorly consolidated, commonly crossbedded, sandstone, but includes micaceous siltstone, and conglomerate. The only detailed mapping of the Tapeats in the reservation was by Finnell (1966a), who reported the thickness of the formation as 0 to 280 ft.

The Martin Formation overlies the Tapeats Sandstone but at most places in the reservation it rests directly on Precambrian rocks. Shale, sandstone, and conglomerate totaling 15 ft thick at the base of the Martin in Flying V Canyon was named the Beckers Butte Member by Teichert (1965). This member probably is very thin or absent elsewhere in the reservation, and most of the rocks that Teichert (1965) identified as the Beckers Butte Member in the area now are thought to belong to the Tapeats Sandstone, although this conclusion has not yet appeared in published reports. The Jerome Member (Teichert, 1965) of the Martin rests on the Beckers Butte Member, is 6 to 400 ft thick, and consists in ascending order of fetid dolomite, aphanitic dolomite, and an upper unit of dolomite, limestone, and shale. These units are transgressive toward the northeast across the reservation as shown by the wedging out of the fetid and aphanitic dolomite units in the vicinity of Chediski Mountain and by an increase in sandstone and shale in the upper unit in a northeasterly direction.

The overlying Redwall Limestone is a distinctive formation because it commonly forms prominent, picturesque cliffs that serve as a stratigraphic marker from the Fort Apache Reservation to the Grand Canyon region. In the reservation it is a light-gray dense to coarsely granular, generally thick bedded limestone 25 to 225 ft thick; many intervals are abundantly fossiliferous and contain numerous fossil corals.

Pennsylvanian Rocks

Pennsylvanian strata of the Naco Formation unconformably overlie the Redwall Limestone and crop out in the western and southern parts of the reservation. The formation consists of interbedded limestone, sandstone, and shale in beds that show considerable lateral variation in thickness and lithology. Basal beds are reddish clastic rocks that filled sink holes and depressions formed during pre-Pennsylvanian weathering of the Redwall Limestone. The Naco is as much as 800 ft thick.

Permian and Pennsylvanian Rocks

The most extensively exposed rocks in the Fort Apache Indian Reservation belong to the Supai

Formation of Permian and Pennsylvanian age. These rocks, about 1,300 ft thick, lie in gradational contact on the Naco Formation and consist largely of reddish-brown sandstone, siltstone, mudstone and subordinate gray limestone, and gypsum. Moore (1968) described the Supai as consisting of three members; however, Winters (1963) recognized four members, and Finnell (1966a, b) and McKay (1972) subdivided the formation into five members. All workers have recognized the Fort Apache Limestone Member in the upper part of the formation, as it forms a prominent cliff that contrasts with the ledge and slope topography of most of the Supai. Gypsum beds as thick as 30 ft (Moore, 1968) and of potential economic significance occur above the Fort Apache Member in the highest member of the formation. According to Peirce and Gerrard (1966) halite has been found in the highest member north of the reservation.

Permian Rocks

Strata of Permian age are exposed high on the ridges in the northern half of the reservation as far east as the North Fork of White River. Rocks of this age comprise the Coconino Sandstone and the overlying Kaihab Limestone, both widely exposed in northern Arizona. The Coconino is distinctive because of its pale yellowish gray to pale orange color and beds 10 to 50 ft thick. Eolian cross-bedding is common in the upper half of the formation. The Coconino is 200 to 450 ft thick. The Kaibab Limestone consists of light-gray limestone and sandstone 0 to 180 ft thick.

Cretaceous Rocks

Sedimentary rocks of Upper Cretaceous age cap many of the high ridges under the Mogollon Rim. These strata total nearly 500 ft in thickness and rest in angular unconformity on Paleozoic formations as low in the stratigraphic section as the Supai Formation. They are pale gray, brown, and red sandstone and shale containing carbonaceous and ferruginous fossil plants. Beds of shaly coal 6 in. to 6 ft thick in the bottom 85 ft of the unit were reported by Finnell (1966a, b) and McKay (1972), and Moore (1968) reported two layers of bituminous to subbituminous coal near the middle of the Cretaceous section.

Tertiary Rocks

<u>Sedimentary Deposits</u>.--A variety of sedimentary deposits of Tertiary age in the reservation rest on all older strata, and are in part overlain by Tertiary volcanic rocks. These deposits include gravels, sandstone, and minor volcanic rocks in the lowlands along the Salt River west of Canyon Creek, gravel and sandstone on ridge crests at gradually increasing altitudes from the Salt River to the Mogollon Rim, and gravel, sandstone, and mudstone and subordinate flows and tuffs from Black River to northwest of Baldy Peak. Probably all of the reservation once was buried in gravel. The gravels on the Mogollon Rim are considered by Peirce and others (1978) as Eocene-Oligocene in age. The sedimentary rocks in the Baldy Peak area may correlate with similar rocks east of the reservation, which were thought by Sirrine (1958) and Wrucke (1961) to be of early to mid-Tertiary

age and which, in turn, correlate with 37 m.y. old andesite in the Blue Range southeast of Mount Baldy (Ratte and others, 1969). An unpublished date of 19 m.y. obtained by the U.S. Geological Survey on tuff interbedded with gravels along Cherry Creek, about 3 miles west of the reservation, indicates that gravels from Cherry Creek to Canyon Creek are at least in part of Miocene age.

Andesite and Basalt.--Overlying the sedimentary deposits in the southeastern part of the reservation are little known lava flows thought to consist largely of andesite and basalt. These rocks possibly are older than mid-Miocene (Luedke and Smith, 1978) and may be coextensive with 23 m.y. old basaltic andesites in the Blue Range southeast of the reservation (Ratte and others, 1969)

Latite.--Resting on the sedimentary deposits of Tertiary age and probably on the andesite and basalt are lava flows and epiclastic rocks of the Baldy Peak volcano (Merrill and Pewe, 1977), whose eroded form dominates the landscape in the eastern part of the reservation. The flows are mostly latite and quartz latite of the Mount Baldy Formation, which is about 1,600 ft thick. They are thought to have been erupted between 12 and 8 m.y. ago (Merrill and Pewe, 1977). Colluvium, lahars, tephra, and mudflows of the Sheep Crossing Formation of Miocene age of Merrill and Pewe (1971) rest on the Mount Baldy Formation and make up a small part of the volcano.

Basalt.--Basalt flows of Miocene and Pliocene age nearly surround Baldy Peak and are clearly younger than the latite and epiclastic rocks that form the mountain (Merrill and Pewe, 1977). The older flows (Figure 2) in this sequence were extruded sometime in the interval 10 to 5 m.y. ago (Luedke and Smith, 1978) and before a late stage of canyon development that incised them on the west and southwest flanks of Baldy Peak. The younger basalt (Figure 2) is about 3 m.y. old (Luedke and Smith, 1978) and postdates the late canyon cutting. This basalt flowed down Carrizo Creek, the north fork of White River, and down Salt River to a point 8 mi west of the junction of Black River and White River. It also blanketed a large area north of Baldy Peak and built numerous cinder cones that dot the landscape today.

Quaternary Deposits

Glacial advances occurred at least four times during the Quarternary Period in the White Mountains, and according to Merrill and Pewe (1977) and Finnell and others (1967) deposited moraines, till, and other deposits in the high parts of the White Mountains. Unconsolidated sand and gravel occupy stream bottoms throughout the area, and clay, gravel, and soil exist in areas of low relief near Whitewater and Carrizo

Structure

The rocks of the Fort Apache Indian Reservation record a complex structural history that belies the generally simple outcrop patterns displayed by the flat-lying younger Precambrian and Phanerozoic layered sequence.

The oldest deformation that affected the rocks exposed on the reservation was folding of the

Redmond Formation before intrusion of the 1,450 m.y. old Ruin Granite. During that deformation the Redmond was tilted to the southeast along a N. 50º E. strike (Cuffney, 1978) that is common to older rocks in central Arizona (Wilson, 1962). Contacts between the Redmond and the Ruin cross this trend, showing that emplacement of the granite followed the tilting.

Extensive disruption of the younger Precambrian stratified rocks accompanied intrusion of diabase as sills and discordant bodies after deposition of the Troy Quartzite. Many normal and reverse faults in these rocks were formed as the intruding diabase magma inflated the host strata and uplifted some overlying blocks more than others nearby. Faults that developed in this manner are clearly shown in the western part of the reservation by Finnell (1966a). Small-scale faults and folds that are adjustments to diabase emplacement in the Mescal Limestone were important in the localization of asbestos deposits, and steep fractures formed by diabase in the Dripping Spring Quartzite may have been significant in the genesis of uranium deposits.

The younger period of deformation is of Cenozoic age and may be related to the uplift of the Colorado Plateau and the development of structures in the Basin and Range province Northwest-trending faults displace Paleozoic rocks in the central and western parts of the reservation and have an overall displacement up to the northeast (Finnell, 1966b; Moore, 1968). Several monoclinal folds occur in the zone of these northwest-trending faults.

One of the most prominent Cenozoic structures on the reservation is the Canyon Creek fault, which trends from the upper reaches of Canyon Creek south-southeast to Salt River and beyond. This fault may have originated during Precambrian folding and faulting that occurred along widely spaced northerly trending narrow belts in the region. Evidence for a Precambrian origin of the part of the fault within the reservation has not been established, but is known for its continuation south of Salt River (Shride, 1967). As interpreted by Finnell (1962), early movement of Tertiary age on this fault displaced beds as much as 1,800 ft down to the east, and later movement displaced Tertiary gravels as much as 1,300 ft down to the west. Both movements may have been synchronous with Basin and Range deformation that locally extended into the Colorado Plateau province.

Baldy Peak volcano lies on a northeast-trending alignment of volcanic fields that extends from the San Carlos Indian Reservation across western New Mexico to Taos (Luedke and Smith, 1978). The alignment of cinder cones in the White Mountains was inferred by Moore (1968) to suggest concealed fractures that trend N. 45º W., N. 60º W., and N. 70º E.

ECONOMIC GEOLOGY

Known Mineral Resources

A variety of metallic minerals, nonmetallic minerals and rocks, and mineral fuels are recognized on the reservation, Iron is the principal metallic resource; only minor amounts of manganese and traces of copper, gold, and silver have been reported. Nonmetallic commodities include asbestos, clay, dimension stone, gypsum, sand and gravel, and rock suitable for construction or decorative uses. Coal and uranium are known mineral fuels. Nonmetallic minerals and rocks have had the greatest production of the mineral commodities in the reservation, and they have the greatest potential for economic development in the foreseeable future.

Most of the known mineral deposits (iron, some copper, gypsum, gravel, limestone, sand, and stone) in the reservation formed by sedimentary processes. The asbestos formed as vein deposits related to metamorphism that accompanied emplacement of diabase intrusions. The manganese ores represent materials carried in thermal waters and deposited at shallow depth; base-metal ores that originated in hydrothermal systems and are comparable to the large copper deposits of the Globe-Miami district are not known on the reservation. The position of the reservation within the Colorado Plateau structural province suggests that the mineral deposits in the reservation should be of different size and character from those in the metal-rich mining districts of the Basin and Range province of southern Arizona.

Metallic Mineral Resources

Iron.--Iron is the most thoroughly investigated metallic mineral resource on the reservation. It occurs as hematite in the carbonate members of the Mescal Limestone along Canyon Creek and its tributaries in the northwestern part of the reservation. The hematite originated as a lateritic residue derived by weathering of the basalt that overlies the Mescal Limestone and was trapped with silica in cavities in the karst terrane formed on the Mescal prior to deposition of the Troy Quartzite (Shride, 1967). Still later in Precambrian time, some hematite was metamorphosed adjacent to diabase intrusions and converted to magnetite. The hematite accumulated as irregular tabular bodies a few inches to about 40 ft thick, having maximum dimensions on the order of 10,000 ft and iron contents ranging from 20 to 68 percent (Stewart, 1947; Harrer, 1964; Shride, 1967).

Manganese.--Manganese occurs as psilomelane, pyrolusite, and wad poorly consolidated in Tertiary gravel and intrusive dikes a mile or two northwest of Salt River near the southwestern corner of the reservation and in the Kaibab Limestone in a tributary of Carrizo Creek 2 mi south of the Mogollon Rim. The manganese minerals fill veins and occur as impregnations in the gravels and volcanic rocks, and they occupy veins in the Kaibab Limestone and occur as residual nodules in soils derived from that formation. The deposits formed at low temperatures, at very shallow depth. Judged by the 10,000 to 12,000 long tons of ore mined in the Salt River area (Farnham, Stewart, and DeLong, 1961), manganese resource in the vicinity of these deposits may range from a few hundred long tons to a few tens of thousands of long tons of ore averaging no more than about 15 percent Mn. Resources in the Kaibab Limestone probably are insignificant.

Related manganese deposits exist in a belt that extends south to Globe and contains ores mined in the 1880's for silver and copper (Farnham, Stewart, and DeLong, 1961). However, silver has not been reported in amounts sufficient to encourage mining. Cobalt reported by Moore (1968) as having been detected in a manganese concentrate from the reservation is a minor constituent observed in a chemical analysis and should not be considered as indicating a cobalt resource.

Copper.--Traces of copper occur on bedding surfaces and in thin fracture seams in the Supai Formation below the Fort Apache Limestone Member (Moore, 1968). Such red-bed copper deposits, numerous in strata of late Paleozoic and Mesozoic age in the western United States (Cox and others, 1973) are thought to have formed during or shortly after deposition of the host sediments. The low content of copper in the Supai Formation suggests that the possibility of minable copper resources of the red-bed type in the reservation are unlikely, but the occurrences should be assessed. Minor occurrences of copper in rocks of the Apache Group and in Precambrian diabase are not indicative of a potential resource.

Quartz veins on the reservation have been sampled for gold and found barren or virtually barren (Moore, 1968). Early-day speculations that placer gold might occur in gravels that cap a divide, vaguely identified by Reagan (1903) as near Cibecue, have not been substantiated.

Nonmetallic Mineral Resources

Asbestos.--Asbestos is the principal nonmetallic mineral commodity in the Fort Apache Indian Reservation. It occurs as low-iron chrysotile in the Mescal Limestone, which crops out only along Salt River Canyon and between Canyon Creek and the western border of the reservation. These areas are parts of the two principal asbestos-producing areas in Gila County (Shride, 1969), which has been the main source of low-iron, long-staple chrysotile asbestos produced in the United States (Stewart and Haury, 1947).

Asbestos occurs in the lower and middle members of the Mescal Limestone where the formation has been invaded and metamorphosed by diabase (Shride, 1967). Most of the asbestos deposits are within 25 ft stratigraphically above or below a diabase sill. The original cherty dolomite of the Mescal was converted to silicated limestone containing tabular layers of calcium and magnesium silicates, of which serpentine is dominant. Chrysotile asbestos may occur throughout the metamorphosed rock, but is localized in minable amounts only where these layers were warped into small folds and broken by small-scale faults in adjustment to diabase intrusion. Many of the folds are so subtle as to be difficult to identify. The asbestos occurs mainly as cross fiber, which fills fissures that range from microscopic to more than an inch in width and parallel the bedding in the host limestone. The typical minable asbestos-serpentine zones are 6 to 18 in. thick, and contain asbestos veins aggregating at least 2 in. in thickness.

The deposits generally are flat lying, elliptical in plan, and elongate parallel to a single fold or linear belt of low-angle faults. These occurrences yield 10 to 50 tons of fiber; exceptionally a few hundred tons have been mined from such deposits. Larger deposits occur where several folds related to diabase intrusion are closely spaced. Deposits of this type may contain a few hundred to several thousand tons of asbestos. The most extensive asbestos deposits occur within stratigraphic intervals 1 to 3 ft and 30 to 40 ft below the top of the lower member of the Mescal.

Additional asbestos resources on the Fort Apache Indian Reservation almost certainly exist where discordant diabase intrusions transect favorable strata at sites not yet exposed to erosion. Using projections from outcrops, hidden deposits could be discovered as much as 1,000 ft behind canyon wall exposures. Asbestos deposits comparable to some of the largest previously exploited in the region could occur along the Salt River Canyon between Canyon Creek and Flying V Canyon, where one to four thick diabase sills split and intricately displaced strata of the Mescal Limestone.

The Canyon Creek area south of the 34th Parallel has a lower potential for asbestos deposits because diabase sills are thin or absent, favorable strata in the Mescal were eroded prior to deposition of the Tertiary gravel and the metamorphosed strata that remain were deeply weathered to the detriment of existing asbestos. North of the 34th Parallel, asbestos is almost nonexistent because most of the carbonate rock was leached from the Mescal during pre-Troy erosion

Gypsum.--Gypsum occurs as sedimentary layers at three stratigraphic zones in the Supai Formation on the fringe of an evaporite-rich basin centered about 30 mi northeast of the reservation (Peirce and Gerrard, 1966). The lowest zone consists of 1 to 3 gypsum beds 1 to 12 ft thick located about 200 ft below the Fort Apache Member. These beds are exposed at several localities within 5-12 miles of Carrizo (Moore, 1968). Another gypsum zone, about 50 ft below the Fort Apache Member, crops out locally in the vicinity of Whiteriver and apparently is thinner than the other two zones. Gypsum layers in a zone above the Fort Apache Member aggregate 0 to 40 ft in thickness and can be traced in two parallel belts for a distance of 30 mi northwest and southeast through Carrizo. Individual layers 11 and 16 ft thick are exposed at one locality and 30 ft thick at another locality, but at other places where the zone is exposed gypsum has been found to reach thicknesses of less than 3 ft (Moore, 1968). Gypsum resources on the reservation probably are large.

Building Stone.--Quartzite from the upper part of the Troy Quartzite, sandstone from the Coconino Sandstone, and limestone from the Redwall Limestone, Naco Formation, and Kaibab Limestone are possible sources for dimension stone. It is doubtful that strata of uniform coloration and splitting properties exist for large-scale quarry operations, but rock is available for local use. Metamorphosed Mescal Limestone, present in large quantities, may contain marble suitable for decorative stone because of attractive irregular masses of included serpentine.

Construction Materials.--Alluvial deposits in stream bottoms and the Tertiary gravels are sources of sand, gravel, and locally of clay, and the Cretaceous sedimentary rocks contain clay. Moore (1968) presented information on the location and quality of clay for bricks. Limestone in Paleozoic strata, and volcanic rocks, particularly from cinder cones in the younger basalt are potential sources of aggregate and are available in large quantities.

Mineral Fuels

Subbituminous Coal.--This fuel occurs in Cretaceous rocks in the northern part of the reservation, and occupies a small part of the Pinedale coal field (Averitt and O'Sullivan, 1969). The coal is in two zones 10 to 15 ft apart, beginning 50 to 100 ft above the base of the Cretaceous strata (Veatch, 1911) The upper zone has a maximum thickness of 12 ft and is about half coal; the lower zone is 2 to 3½ ft thick and contains a higher proportion of coal. The lower zone is the principal one exposed on the reservation and was mined at least briefly for local use. Moore (1968) shows coal at several localities in a northwest-trending belt 26 mi long that passes between Carrizo and Forestdale. The supply of coal from the Pinedale field is said to be sufficient for modest local demand (Averitt and O'Sullivan, 1969).

Uranium.--The upper member of the Dripping Spring Quartzite has been prospected for uranium along Canyon Creek and in Rock Canyon in the western part of the reservation. Workings at the Rock Canyon deposit expose steeply dipping uraninite-bearing veins in thin-bedded carbonaceous siltstone of the nearly black, highly pyritic carbonaceous strata of the black facies in the upper member of the Dripping Spring (Granger and Raup, 1969a). The black facies, which is the principal host for uranium deposits, is exposed from the walls of Canyon Creek west to the reservation boundary and upstream in the Salt River Canyon at least as far as Flying V Canyon.

Granger and Raup (1969b) concluded that the diabase furnished the uranium for the deposits in the Dripping Spring Quartzite. The genetic relationship of the uranium to the diabase is suggested by the close spatial association of the deposits to diabase bodies, the high temperature origin of the uraninite in the veins, the similar ages of the uraninite and the diabase, and the apparent loss of uranium from the diabase as it cooled. However, Otton (see Otton and others, 1980) believed that the uranium in the black facies is of syngenetic origin and was mobilized and redistributed in faults and fractures by hydrothermal fluids that originated during emplacement of the diabase.

The black facies of the upper Dripping Spring Quartzite in the reservation has potential for additional uranium deposits. Uranium mineralization on the reservation is found in the same Reologic environment as it is to the west in the Sierra Ancha region, where deposits range in grade from .01-.30 percent U_3O_8 and contain 100,000 pounds or more of U_3O_8 (Otton and others, 1980). Presumably deposits on the reservation could be comparable.

Potential Mineral Resources

Geothermal Energy.--Resources of geothermal energy have not been found on the Fort Apache Indian Reservation. Geothermal energy requires a suitable heat reservoir, and today the best geothermal reservoirs in the world are in areas containing igneous systems less than 1 m.y. old (Luedke and Smith, 1978). Older systems have progressively lower potential with increasing age. Moreover, silicic igneous rocks, because they commonly form from bodies high in the Earth's crust, generally are considered to have a higher potential for geothermal energy than rocks relatively low in silica, such as basalt, that have sources below the crust. The youngest igneous rocks identified on the reservation are the younger basalts thought to be about 3 m.y. old. These rocks and the older basalts and andesite have no associated silicic rocks and therefore are poor candidates as sources of geothermal energy. The latite of Baldy Peak may overlie a reservoir containing heat at high crustal levels, but its age in the 8 to 12 m.y. range indicates that it has at best a low potential for geothermal energy.

Oil and Gas.--The petroleum potential of central and northeastern Arizona was summarized by Huddle and Dobrovolny (1945), who showed the location of wells drilled as close as 25 mi north of the reservation. The only indication of petroleum on the reservation is a petroliferous odor emitted from fresh breaks in calcareous rocks in the Martin Formation and in the Fort Apache Member and locally other limestones of the Supai Formation. Only a low probability of significant oil and gas resources exists in rocks of the reservation.

MINERAL RESOURCES

Known mineral resources within the Fort Apache Indian Reservation include coal, iron, manganese, asbestos, gypsum, clay, limestone, sand and gravel, scoria, and clay, as well as various stone resources, such as sandstone, serpentine, and perhaps marble. Minor occurrences of copper, gold, and salt are mentioned in the literature, but have not been extensively investigated.

Recorded production of mineral resources has been limited to iron, manganese, asbestos, sand and gravel, and scoria. Coal has been mined on the reservation to a limited extent, according to the USGS, and the area is prospective for petroleum and natural gas and geothermal resources. Occurrences of decorative materials are present, possibly in quantities large enough to be collected to support a small business enterprise.

Fuel Resources

Known fuel resources on the reservation are limited to coal and possibly uranium. Occurrences of neither commodity have been investigated extensively. Two exploratory holes were drilled for oil and gas, but both were dry. Potential geothermal areas have not been tested.

Coal

Coal on the Fort Apache Reservation is in the Pinedale coalfield. Because coal exploration has been negligible, information is sparse. Veatch (1911, p. 239-242) notes that the coal is of Upper Cretaceous Age He reported examining coal in two prospect pits. The first in NE¼NE¼, sec. 36, T. 11 N., R 18 E. showed two beds 10 to 15 feet apart. The upper bed is described as being 12 feet thick, about one-half of which is "dirty" coal, and the remaining 6 feet is interbedded with rock (Andrews, Hendricks, and Huddle, 1947, p. 3). The lower bed, Veatch reports, is 2 to 3 feet of very good subbituminous coal. The other prospect pit is in sec. 26, T. 11 N., R. 18 E. A description of the coal is not given, but an analysis of the lower 4 feet of the upper bed gave 57 percent ash and the lower bed 10 percent ash. Andrews and others (1947, pg

32-33) analyzed three samples of the coal, and results showed that they contained between 16 and 42 percent ash, 2 to 5 percent sulfur, and 25 to 50 percent fixed carbon. The Arizona Bureau of Mines (Moore, 1968, p. 78) sampled and analyzed the coal, reporting that only one of six samples contained less than 24 percent ash and four samples contained ash exceeding 40 percent.

Although available information indicates that the coal on the reservation has little economic value, the BIA operated a small coal mine in SW¼NW¼ sec. 9, T. 7 N., R. 23 E. (Figure 3) The quantity of coal mined is not known, but Andrews and others (1947, p. 3) state that the bed was about 3.5 feet thick, of which about one-third was "bone" (rock).

Neither the quantity nor the quality of the coal on the reservation are well known. The Pinedale coalfield extends over a fairly large area (Figure 3), but it is unknown whether the beds are continuous or even present over the entire field; only a few samples have been analyzed, and they apparently were taken from outcrop areas and may not be representative of the coal throughout the field. The USGS considers the northern edge (Figure 3) of the reservation prospectively valuable for coal (Haigler and Brook, 1978).

Geothermal Resources

Little is known of the geothermal resource potential on reservation land. Alto, Lee, and Throckmorton (1979), however, show two areas in the southwestern part of the reservation (Figure 3) that they consider potentially valuable for geothermal resources. Haman, Stone, and Witcher (1978) do not cite the areas shown by Alto, Lee, and Throckmorton, but they imply that the eastern half of the reservation, which is covered by recent volcanic rocks, may hold some potential for such resources. Owing to the lack of information, the geothermal potential of the area cannot be assessed without an extensive exploration program.

Petroleum and Natural Gas

Petroleum and natural gas have not been discovered on the reservation, although two exploratory holes were drilled during 1966-67 by Tenneco Inc. One hole, in sec. 31, T. 10 N., R. 21 E., was drilled to 825 feet and abandoned. The other, in NE¼SE¼ sec. 31, T. 10 N., R. 21 E., was abandoned after encountering granite at 4,059 feet. Tenneco obtained leases for oil and was exploration on 40,229 acres. The bonus was $1.35 per acre, for which the tribe received in excess of $54,000. The Tenneco leases were canceled in 1967. In 1964, Humble Oil Corp. leased the entire reservation for oil and gas exploration, except for areas covered by CF&I iron leases, but the lease was relinquished in 1965 or 1966 without drilling a test hole.

Because so little exploration has occurred on the reservation, it is difficult to evaluate the oil and gas potential. Nevertheless, the USGS (Stipp, 1960) rates much of the reservation as prospectively valuable for oil and gas (Figure 3).

Uranium

Little is known of the uranium potential of Fort Apache land. Two anomalies, however, have been briefly described by Peirce, Keith, and Wilt (1970, p. 250, 274, and 277). The authors describe the first location as NW¼ sec. 11, T. 8 N., R. 17 E., near Cibecue (Figure 3), where uranium and copper oxides occur in a gray, limey mudstone in the Permian-Pennsylvanian Supai Formation. The other location is in NW¼ sec. 14, T. 5 N., R. 16 E. That deposit is characterized as a vein in the Precambrian Dripping Springs Quartzite, and the uranium occurs along with pyrite, limonite, and sulfates. About 5 tons of stockpiled ore have been reported.

An occurrence mentioned by the same authors is just across the Salt River from the Fort Apache Reservation. This property apparently yielded about 140 tons of ore grading about 0.16 percent U_3O_8. It, and the other occurrence cited, indicate that the Dripping Springs Quartzite, which is exposed over a large area in the southwest part of the reservation, may hold some potential for significant uranium discovery. Moreover, Peirce, Jones, and Rogers (1977, p. 40) believe "...that several hundreds of square miles of favorable exploration ground exist on the Fort Apache Reservation less than 500 feet below the surface."

Overall, the reservation has not been extensively explored for uranium. Although some potential for discovery exists, that potential cannot be assessed prior to detailed exploration

Metallic Resources

Significant metallic mineral resources on Fort Apache land are limited to iron and manganese. Gold is thought to occur in placer deposits and possibly some lode deposits. Minor occurrences of copper are known, and cobalt is mentioned but has not been investigated.

Iron deposits have been extensively explored and more than 175,000 tons of ore produced. Manganese has been produced in minor quantities from two deposits, but the ore was found to have a copper content too high to meet specifications.

Cobalt

Minor occurrences of cobalt have been reported on the Fort Apache Reservation. Cobalt has been detected in small quantities along with copper in the manganese deposits (Moore, 1968, p. 42). Moore also notes that an unconfirmed occurrence of cobalt is reported about half a mile upstream from the Oxbow Bend (Mule Shoe) of the Salt River. These occurrences are probably of academic interest only.

Copper

Copper occurrences have been noted on Fort Apache land (Moore, 1968, p. 42, 61-62), but no recorded production has occurred. Apparently, very minor copper occurs with diabase sills and in the manganese deposits. According to Moore, these deposits are of no importance Another area in which minor quantities of copper have been found is that part of the reservation underlain by the Supai Formation. Arizona Bureau of Mines personnel list four deposits, two in sec. 11, T. 6 N., R. 21 E., one in sec. 2, T. 6 N., R. 21 E., and one in sec. 24, T. 7 N., R. 18 E. (Figure 4). According to Moore (1968, p. 62), the " :..visible copper mineralization occurs as malachite ($Cu_2CO_3(OH)_2$) along bedding planes and minute fractures in a thin bed of dark gray to black, fissile siltstone." At one location (sec. 11, T. 6 N., R. 21 E.), two samples were taken that assayed 0.15 and 0.01 percent copper. At the exposures in sec. 24, T. 7 N., R. 18 E., a ½-inch showing assayed 0.58 percent copper, and an 18-inch showing at the same locality assayed 0.19 percent copper. Moore (1968, p. 62), comments on these deposits:

> All of the deposits occur at about the same horizon in the Supai Formation, between 350 to 400 feet below the Fort Apache Limestone. The mineralization is stratigraphically controlled and, although no commercial importance is attached to the exposures thus far discovered, the possibility of finding additional deposits of better grade in the same horizon should be considered.

Gold

No gold production has been recorded from the Fort Apache Reservation. Moore (1968, p. 80), however, cites unconfirmed reports that as much as $4.00 per day of gold was recovered from placers on Diamond Creek (Figure 1). Moore (1968, p. 41) also reports that samples from 13 quartz veins in the Canyon Creek-Salt River Canyon area yielded values of no more than traces of gold. Reagan (1911, p. 306) also reports gold in Quaternary gravels near Cibecue. However, Moore (1968, p. 62) indicates that although the gravels were derived from Precambrian rock known to contain gold, it is unlikely that the deposits are of sufficient size or grade to warrant exploitation.

Overall, it would appear that some gold occurs on the reservation, but it is unlikely that it could be economically recovered.

Iron

Iron deposits on the Fort Apache Indian reservation have been known since around 1890 (Harrer, 1964, p. 73). Apparently, the earliest attempt to exploit the resource was during the 1920's. Although claims were staked by H. S. Colcord at that time, there was no commercial extraction of ore until 1966. The deposits have been investigated by the Bureau of Mines (Stewart, 1947, and Harrer, 1964), and the USGS (Burchard, 1930). In 1966, the Colorado Fuel and Iron Steel Corp. (CF&I) explored the deposits and removed some ore for testing purposes. The lease held by CF&I Steel Corp. was terminated by the Tribal Council in 1977.

BIA records do not indicate how much ore was removed by CF&I between 1966, when the deposit first was sampled for testing purposes, and June 1968 when commercial production began. However, the company removed about 176,500 long tons of ore between June of 1968 and April 1976. Tonnages cited for iron ore in this report are in long tons. Table 2 shows ore production and royalty by year during the period of mining activity.

TABLE 2

Iron Production From Fort Apache Indian Reservation Between 1968 and 1977*

Year	Production (tons)**	Royalty***
1968	13,295	$ 2,117.00
1969	16,443	3,285.00
1970	11,601	3,337.00
1971	14,843	1,968.00
1972	14,778	1,956.00
1973	10,654	2,145.00
1974	48,399	7,709.00
1975	36,475	6,819.00
1976	10,047	2,009.00
1977	0	0
Total	176,535	$32,235.00

*Source BIA Records

**Figures rounded to nearest long ton

***Figures rounded to the nearest dollar and do not include yearly rental or bonus payments.

According to Harrer (1964, p. 73), the iron ore on the Fort Apache Reservation is part of a large area of iron occurrences some 90 miles long and 36 miles wide that extends between the towns of Globe and Young in Arizona. All significant iron deposits on the reservation occur in a belt 1 mile on either side of Canyon Creek near the western boundary (Figure 4). Other small iron ore exposures are known outside this belt, but they have little or no economic significance, according to Stewart (1947, p. 22). The most important deposit, and the only one that has been mined, is the Apache deposit. Other significant deposits include the Chediski Hematite, Cow Creek Hematite, Marley-Grasshopper Hematite, Oak Creek (Grasshopper Ranch) Hematite, and Split Rock (Gentry-Rock Creek) Hematite (Harrer, 1964, p. 72-81).

Apache Hematite Deposit

Two occurrences, East Apache (Swamp Creek Mountain) and West Apache (Bear Spring Mountain), make up the Apache deposit. According to Harrer (1964, p. 24), the deposits are in secs. 25, 26, and 35, T. 9 N., R. 15½ E. Moore, however, gives the location in secs. 10, 15, and 16, T. 9 N., R. 15½ E. According to a USGS topographic map (scale 1:100,000), Moore's location is correct. Harrer's location was based on Bureau of Land Management projections prior to the printing of the USGS map and apparently is incorrect.

Harrer states (1964, p. 74) that "Hematite occurs widely as more or less bedded, contact-metamorphic and pyrometasomatic replacements of Mescal Limestone closely associated with diabase intrusives." The East Apache deposit can be traced for about 12,000 feet along the outcrop and ranges between 3 and 47 feet thick. According to Harrer (p. 74), the West Apache deposit is a continuation of the East Apache deposit and can be traced for about 5,000 feet along the outcrop (Figure 5). Apparently the thickness of the ore of the West deposit is about the same as that of the East deposit.

Harrer (1964, p. 74) describes the ore as ranging:

> ...from nearly pure red to bluish-black hematite and some specularite to beds interlayered and mixed with chert, jasperoid, sandstone, and shale. Much of the hematite is fine-grained and massive, containing as much as l percent apatite and 3-5 percent sericite. The hematite ranges in texture from hard and dense to soft and earthy. The lower grade hematite is generally harder and more massive.

The Bureau of Mines examined and sampled the Apache deposits between 1942 and 1945, and Harrer (1964, p. 74) reports that:

> The average of all trench sampling and core drilling done was 46.8 percent iron. Three carloads of ore mined from the best appearing outcrop area at East Apache contained 63.96 percent iron, 0.06 percent titania, 0.038 percent sulfur, 0.186 percent phosphorus, 6.88 percent silica, 0.46 percent lime, 1.15 percent alumina, and 7.36 percent insoluble.

The literature does not provide a precise estimate of ore contained in the Apache deposits, but Burchard (1930, p. 75) indicates that there is at least 10 million tons, and Harrer (1964, p. 77) estimates that the deposits contain multi-million tons of 46 to 67 percent iron.

The Colorado Fuel and Iron Corp. acquired leases to the Apache deposits in 1960, and by 1977, when the leases were terminated, only about 176,000 tons of ore had been removed. Therefore, the Apache deposits represent a large and valuable economic mineral resource of the Fort Apache Indian tribe.

Chediski Deposit

The Chediski iron deposit is in secs. 27, 34, and 35, T. 9 N., R. 15½ E. (Moore, 1968, p. 31). According to Harrer (1964, p. 79), the geology is similar to the Apache deposit. Harrer states:

> Hematite of varying quality is exposed for about a mile in an arcuate outcrop on the east slope of Chediski Ridge, 300 to 700 feet above Canyon Creek, southwest of its confluence with Willow Creek. A second outcrop is traceable at Canyon Creek level about 0.3 miles above its confluence with Willow Creek. The northwest end of this outcrop is about 30 feet above the creek bed and is covered by talus. Outcrops along the northeast bank of Canyon Creek show 2 to 10 feet of hematite interlayered with siliceous and ferruginous material. The hematite-rich formation on the Chediski Ridge is 2 to 21 feet thick with 23- to 61.5-

percent iron content. A 2,000-foot length near the south end of the Chediski outcrop averaged 18.7 feet in thickness, having a 42.21-percent iron content. The hematite-rich bed is cut off on the north by a fault. It can be traced south and east interruptedly for several miles farther, but it appears to consist chiefly of lowgrade ferruginous to barren material that is interlayered with occasional, discontinuous lenses of high-grade hematite; this is an outcrop impression.

The Bureau of Mines investigated and sampled the Chediski deposit between 1942 and 1945 (Stewart, 1947, p. 14), cutting 14 trenches, but no drilling was undertaken. Harrer (1964, p 80) indicates that the results of the sampling gave an average composition of the Chediski hematite, exclusive of interbedded low-grade material and barren rock, as "...48.92 percent iron, 0.10 percent manganese, 23.02 percent silica, 0.285 percent phosphorus, 0.055 percent sulfur, 1 01 percent lime, and 2.26 percent alumina." Moore (1968, p. 32), averaging figures reported by Stewart (1947, p. 16), states that the Chediski deposit has an average thickness of 18.7 feet over a 2,000-foot length and an average grade of 49.21 percent iron. No reserve figures from the Chediski deposit were given in any reference.

Cow Creek Hematite

The Cow Creek Hematite deposit is reported by Moore (1968, p. 35) as being in sec. 3, T. 9 N., R. 15½ E. This occurrence is a replacement in Mescal Limestone (Harrer, 1964, p. 80); no other information is known of the deposit.

Marley-Grasshopper Hematite

Harrer (1964, p. 80) reports a hematite occurrence of varying quality about 10 to 12 feet thick in the Oak Creek watershed (Figure 4). Moore (1968, p. 35) reports this deposit as being in sec 12, T 8 N, R. 15½ E., but no other information is available concerning it.

Oak Creek (Grasshopper Ranch) Hematite

The Oak Creek Ranch deposit is reported by Moore (1968, p. 33) as occurring in sec. 31, T. 8 N., R. 16 E. Harrer (1964, p. 80-81) describes this occurrence as:

> A hematite outcrop in Mescal limestone is exposed along the east side Oak Creek Valley (62, fig. 1) a few hundred feet below the rim. The hematite bed, of varying quality, crosses a steep road between Grasshopper Ranch and Oak Creek, about 4 miles west-southwest of the ranch. The hematite bed strikes N 30º E, and it dips 30º southeast. The outcrop was traced about 1,000 feet and reportedly continues for more than a mile. It continues also south of the road for a considerable length. A character sample taken by the Bureau was cut across an 8-foot-bed thickness, including 1.5 feet of lean chert and 1.0 feet of material considered low grade. The sample contained 36.70 percent iron, 38.60

percent silica, 0.1 percent manganese, 0.212 percent phosphorus, and 0.416 percent sulfur. Some exposures appeared comparable to the hematite of the Apache and Chediski deposits but others were poorer.

Split Rock (Gentry-Rock Creek) Hematite

The Split Rock deposit occurs in secs. 22, 23, 27, 28, and 34, T. 8 N., R. 15½ E. (Moore, 1968, p. 34). Apparently, this exposure is similar to the others on the reservation. However, according to Moore (p. 35), the Split Rock area is complicated by numerous faults. Harrer (1964, p. 81) states:

> A character sample taken by the Bureau in 1961 contained 67.9 percent iron, 0.4 percent manganese, 0.2 percent titania, 0.14 percent phosphorus, 0.05 percent sulfur, and 2.4 percent silica.
>
> East of Canyon Creek the hematite is sufficiently shallow for consideration as a limited open-pit area. West of Canyon Creek the hematite is more deeply buried.

Reserves and Mining

Although there are no published iron ore reserve figures for each deposit on the Fort Apache Indian Reservation, Harrer (1964, p. 189) estimates 14.1 million long tons of ore containing at least 46 percent iron and more than 100 million long tons containing more than 20 percent iron. It is possible that more ore than Harrer estimated is available on Indian land, but it would require an expensive and lengthy exploration program to prove such a theory.

All indications are that iron could be economically mined from some of the deposits on the reservation. The Apache deposit had yielded about 175,000 long tons of ore by the time the tribe terminated the CF&I lease in 1977. The lease was not terminated because of a lack of ore but because of a dispute between the tribe and the company. Many millions of tons of ore remain to be removed from the Apache deposits. The Chediski, Oak Creek, and Split Rock deposits may all contain commercial ore.

It has been proven that the Apache deposit is amenable to open-pit mining, and Harrer (1964, p. 81) indicates that part of the Split Rock deposit is sufficiently shallow to be mined by open-pit methods. The Chediski, part of the Apache, the Oak Creek, and parts of the Split Rock deposits probably would require underground mining methods.

Manganese

Manganese has been mined in limited quantities from deposits on the Fort Apache Reservation. Apparently two deposits were exploited to a minor extent between 1939 and 1955 or 1956. According to Moore (1968, p. 61), manganese is also known to occur in minor quantities in the Kaibab Formation in T. 10 N., R. 17 E. (Figure 4). The same author indicated that the Buckskin Canyon deposits are not commercial.

Apache Property

The Apache manganese property is in SW¼ sec. 30, T. 5 N., R. 16 E. (Figure 4). Bureau of Mines engineers visited and sampled the property in 1957 (Farnham and others, 1961, p. 81-84). They report that between 1939 and 1943, 302 long tons of ore was shipped from the property. The handsorted ore contained between 45.3 and 48.7 percent manganese. In 1955, the mine was reopened and a concentrating plant was built near the Salt River. BIA records indicate that 10,000 to 12,000 tons of ore was mined from which 1,540 tons of concentrates were obtained. Some concentrates, according to Farnham, were shipped to a U.S. Government stockpile at Deming, N. Mex., but were found to contain 0.25 percent copper and thus failed to meet government stockpile specifications. What remained of the concentrates were shipped to Arkansas to be blended with copper-free ore, thus reducing the copper content enough to meet specifications. However, transportation and blending apparently proved so costly that the operation was uneconomic. The mill was removed, and the property has remained idle since 1956. Farnham and others (1961) describe the manganese deposits as occurring:

> ...in fracture zones in partly consolidated beds of gravel resembling the Gila conglomerate. The gravels cover many square miles near the southwest corner of the Fort Apache Indian Reservation. They are composed of various-size fragments of many types of rocks with a large proportion of round pebbles and boulders of quartz. In places the beds are known to be at least several hundred feet thick, and in other places they have been eroded completely. Near the manganese deposits the gravels range from a few feet to at least 100 feet in thickness and, judged from a few bedrock exposures, appear to rest upon an uneven erosional surface of igneous rocks similar in appearance to the diabase farther east in Salt River Canyon.
>
> The principal manganese exposures on the property lie in four zones along a northerly trending belt some 2,000 feet long. Intervening areas are largely covered with alluvium and detritus. This covering obscures the correlation of the different exposures and conceals any further extent they may have. The deposits occur in steeply dipping fracture zones that range in strike from northwest to northeast. The zones differ in width, the manganese oxide minerals occurring in narrow veins, interlacing seams, and small nodular masses distributed erratically in the sheared and shattered gravel beds. Psilomelane and minor amounts of the softer oxides are the chief manganese minerals. The gangue is composed largely of quartz, unreplaced pebbles and fragments of gravel.

Farnham and others (1961) also describe the mining operation:

> In the exploited deposit near the southern end of the property, the mineralized zone

was about 25 feet wide and was exposed in an open cut about 60 feet along its southeastward strike. The face of the cut was approximately 23 feet high and contained three enriched veins ranging from 1 to 2 feet in width. These higher grade veins extended from the surface to the bottom of the opening and were separated by lower grade material composed of a network of narrow seams, stringers, and small bunches of manganese minerals. Near its face, the open cut had broken into some old adit workings driven on one of the higher grade veins, which probably was the source of some of the ore produced in 1941. Overburden surrounded the open cut and concealed the further extent of the deposit along the strike.

A few hundred feet farther south, stripping had exposed scattered spots of manganese minerals in an irregular area about 150 feet long and 50 feet wide. The exploratory work had not been completed, and the extent of the deposition in this area was not evident when the property was visited.

Approximately 250 feet north of the first-described zone, the largest and most productive of the deposits was exposed in open cut workings about 300 feet along its northerly trend. In this area the deposit appeared to be as much as 60 feet wide near the south end of the cut and not more than 20 feet wide at the north end. This zone contained vein like strands and irregular masses of higher grade ore, surrounded by interlacing seams and stringers of psilomelane filling the minor fractures in the shattered gravels. The open cut workings reached a maximum depth of some 25 feet. Old reports indicate that some ore was mined in 1941 from this zone in deeper adit workings underlying parts of the present open cut.

About 140 feet north of the open cut, a 30-foot adit had been driven along a well-mineralized vertical fracture striking N. 25º E. and ranging from 1 to 2 feet in width. Here also the gravel adjacent to the higher grade fracture was impregnated with seams and stringers of manganese minerals. The full width of this lower grade material was not exposed.

A few scattered shallow opencuts and pits had explored the zone for some 200 feet along its strike to the northeast.

The northernmost deposit is about 1,000 feet north of the largest open cut. In this area the manganese minerals occurred along a vertical fracture zone striking N. 65º E. It ranged from 10 to 25 feet in width and was exposed in an open cut about 100 feet along the strike. To the northeast, beyond the face of the cut, the deposit was covered with 15 to 20 feet of detritus. Some of this covering had been stripped, exposing the top of the deposit for an additional 60 feet. Some stripping also had been done along the trend of the zone southwest of the cut, but no appreciable amount of ore was exposed by the work. The ore minerals in this deposit, as in the others, occurred in enriched strands and irregular bunches separated by a network of seams and stringers of psilomelane surrounding the pebbles and other constituents of the gravel. Samples taken by Farnham showed that the ore contained 8.4 percent manganese, 3.6 percent $CaCO_3$, and 0.19 percent copper. Further testing showed that it is possible to recover a copper-free, metallurgical-grade product by chemical treatment, but the cost of such treatment was not given.

Accord Deposit

The Accord manganese deposit, according to Moore (1968, p. 37), is in SW¼ sec. 25, T. 5 N., R. 15½ E. (Figure 4). Farnham and others (1961, p. 85) and Moore (1968, p. 39) state that manganese mineralization at the Accord property is similar to that at the Apache manganese deposit about 1.25 miles east. Farnham states:

> Manganese minerals occur along two northerly trending veins about 300 feet apart. In places the veins are enclosed in gravel or conglomerate beds similar to those found on the Apache claims, and in other places they cut intrusive volcanic rocks. The better mineralized parts of the veins range from 1 to 2.5 feet in width and dip steeply westward. The east vein can be traced about 400 feet along the surface by infrequent outcrops, and the west vein is exposed some 70 feet along the strike. The chief manganese minerals are psilomelane and wad, which occur as veinlets and small lenses in a gangue of black and white calcite.
>
> The workings comprised three adits along the east vein and a 15-foot shaft and two shallow opencuts on the west vein. One adit followed the vein about 50 feet, and the two farther north were caved and inaccessible

.

Reserves

No figures are available concerning reserves of manganese on the reservation. However, Moore (1968, p. 39) states that under present market conditions, these manganese deposits do not represent commercially attractive properties, owing to their small size, copper content, and remote location.

Silver

According to Moore (1968, p. 41), silver occurs with manganese at the Apache manganese deposit. An assay of an ore sample from the property showed 0.1 oz. silver per ton. No other references to silver on the reservation could be found.

Nonmetallic Resources

Nonmetallic mineral resources on the reservation include asbestos, clay, gypsum, limestone, salt, sand and gravel, scoria, specialty sands, stone, and minor turquoise (Figure 6). It is possible that gem quality olivine (peridot) occurs within the area underlain by extrusive igneous (basalt, scoria) rocks. Production of nonmetallic minerals has been limited to asbestos, scoria, sand and gravel, clay, minor turquoise, and decorative materials.

Asbestos

The asbestos deposits on the Fort Apache Reservation have been known since before the turn of the century; however, no production was recorded prior to 1921. Arizona, and more particularly Fort Apache asbestos, has been described by Stewart and Haury (1947, p. 11). Stewart explains that asbestos is a commercial term applied to several mineral species that differ widely in chemical composition. Fort Apache asbestos is chrysotile, a hydrous magnesium silicate. Stewart and Haury (1947, p. 11) report:

> There are two types of cross-fiber chrysotile - soft and harsh. Soft fiber feels smooth or soapy and can be twisted and bent between the fingers, and individual fibers are extremely flexible and strong. The longer fibers of this type represent the spinning grades. Harsh fiber is splintery, prickly, and somewhat brittle, so that a small bundle of it breaks if twisted a number of times.
>
> All gradations between harsh, brittle fiber and silky, soft fiber can be found in the district. Probably two-thirds of the asbestos exposed in the various mines and prospects is soft fiber. A vein of soft fiber may lie close to a vein of harsh fiber in the same mine. At some places an asbestos vein changes from soft to harsh fiber; or vice versa, in a few feet. Some mines have only harsh fiber.

When separated from the rock and all gritty particles, most of the chrysotile asbestos exhibits extreme delicacy and silkiness to the touch, with great adaptability for spinning. All fibers exhibit the grouping together of numerous fine threads within what appears to be a single fiber. The actual size of the fiber - that is, the diameter is consequently indefinite, and although careful measurements have been made, which show that the smallest diameter so far determined is 0.00075 millimeter, it can be demonstrated that even the finest filament measured is composed of finer threads.

The asbestos deposits on the reservation occur in the Cambrian Mescal Limestone that has been intruded by diabase sills. According to Wilson (1928, p. 28), "The asbestos invariably occurs with serpentine in limestone, not far from an intrusive contact of diabase." The diabase often intrudes the limestone along bedding planes, and solutions from the diabase used fissures in the limestone as conduits to deposit the serpentine and asbestos.

Asbestos was discovered on Fort Apache land in 1892 (Moore, 1968, p. 42), but production did not begin until 1921. Production was carried out intermittently until 1967, after which no production has been recorded. Moore (1968, p. 43) estimates that between 4,000 and 5,000 tons of asbestos were produced from eight properties on the reservation between 1921 and 1967.

Apache Mine (Crown Asbestos Mines, Inc.)

According to Stewart (1955, p. 36-40), the Apache mine is a group of 20 claims in secs. 7 and 8, T. 5 N., R. 17 E. (Figure 6). The property was first worked around 1923, but most of the production occurred intermittently during 1938-1941, 1948-1949, and 1951-1954. No records could be located for production after 1954, but it is possible that some mineral was produced from the property after that date. Several lessees have operated the property, but the last operator of record was Crown Asbestos Mines Inc. They acquired the lease in 1953.

The deposit is in the Mescal Limestone that has been intruded by diabase sills. Stewart (1955, p. 37) describes the deposit as being:

> ...located on the precipitous west side of Salt River Draw. On the canyon wall, the full thickness of the Mescal formation is exposed, underlain and overlain, respectively, by Dripping Spring and Troy quartzite. A thick diabase sill separates the Mescal and Troy Formations, and two generally concordant sills have split the lower limestone member. Of the two lower sills, the upper is more than 50 feet thick. The lower has a thickness varying from 5 to 10 feet. Between the two, a 10- to 20-foot stratum of limestone is present.
>
> This thin limestone unit can be traced intermittently along the canyon wall for over 3,000 feet. At various places along this outcrop where the exposures are accessible, a serpentine zone usually is present near the top of the stratum. In general, this zone is asbestos bearing, containing from traces to more than 1 inch of asbestos, and at the two mined areas it contained several inches of soft fiber. This horizon is approximately 40 feet stratigraphically below the base of the algal member.

The workings, in 1955, consisted of two separate mines. Mine No. 1 is located on claim No. 5, in a group of 18 claims making up Apache group (Figure 7). The ore zone was developed to a depth of 500 feet with a stope width of 250 feet. According to Stewart (p. 37), the deposit has been localized by a belt of moderate thrust faulting that deformed the beds and caused an increase in fiber content. Stewart further states that:

> Within the mine, the serpentine zone varied from 8 to 18 inches in thickness and contained fiber veins, usually close together, that ranged from 1 to 3½ inches in total thickness. Lenses have been mined that contained considerably more asbestos than is indicated above. The limestone in this area is 10 to 12 feet thick, and the ore zone is approximately 3 feet below the overlying diabase contact.

The No. 2 mine is described as being on claim No. 9 (Figure 7) about one-half mile north of the

No. 1. Stewart indicated at the time he visited the property that it consisted of four adits, 40 to 90 feet in length, over an exposed face about 200 feet long. Apparently little stoping has occurred. The serpentinized zone at the No. 2 mine was 8 to 10 inches thick and contained 1.5 to 4 inches of fiber. Some work has been done at a prospect on Claim No. 1 (Figure 7) about one-half mile south of Mine No. 1. Decreasing mineralization was shown in two adits about 40 feet long.

Apache Extension Group

This property is adjacent to the Apache property and is in sec. 8, T. 5 N., R. 17 E. (Figure 7). Stewart (1955, p. 40) describes the geology of the deposit as similar to the Apache deposit. The mine workings consist of an adit, a stope, and two open cuts. The author characterized the mineralization at this property as:

> A shattered zone at the portal contains a total of 3 to 4 inches of weathered fiber. Within the adit and stope, the 12-inch serpentine band contains an average of more than 1 inch of fiber. The north face of the stope exposes up to a total of 2 inches. The thickest veinlet is found invariably at the bottom of the serpentine band, where fibers reach a maximum length of ¾ inch. The remainder of the asbestos is scattered in veinlets throughout the zone.
>
> The serpentine band here is midway between the overlying and underlying diabase contacts. The upper sill is 50 or more feet thick; the lower sill is generally 10 feet thick.
>
> Overburden obscures the limestone to the northwest, but along the outcrop southeastward three pits have been dug. At 350 feet from the mine, a cut exposes 8 inches of serpentine containing more than 1 inch of short-fiber veinlets. The underlying sill here is 3½ feet thick.
>
> A second cut 250 feet from the mine shows many fiber veinlets. Except in the shallow weathered zone, all the fiber in this deposit is very soft and of excellent tensile strength.

Stansbury Deposit

This deposit is in sec. 30, T. 6 N., R. 19 E. (Figure 6). It is in the Mescal Limestone cut by diabase sills. In the open cuts and exposed outcrops, numerous asbestos-bearing zones are exposed (Stewart, 1955, p. 43). The deposit appears to have been explored by several opencuts and two short inclines. Stewart (1955, p. 43) describes three continuous zones, in massive limestone, but states that the fiber content is variable. The other zones are thin and discontinuous and would cause serious mining problems.

White Tail Group (Horse Shoe Nos. 1 and 2, and Enders Nos. 1 and 2)

This property is in sec. 23, T. 5 N., R. 17 E. (Figure 6). According to Moore (1968, p. 45), the mine was first worked in 1921. The property is not known to have been worked since 1957. Moore further states that total production figures are not available but that less than 150 tons of ore was produced between 1935 and 1967.

Stewart (1955, p. 46-47) describes the mine workings at the White Tail Group:

> Horse Shoe.--On the west side of the ridge, asbestos was mined from a thrust fault zone that is 20 feet above the base of the algal member. The serpentinization was strong and contained numerous veins of soft fiber. This zone was stoped to a depth of 30 feet in stopes nearly 100 feet long. A surface pillar exposed 5 feet of fractured and sheared serpentine, which contained more than 100 asbestos veinlets, some of which contained slip fiber.
>
> At the portal of an adit under these workings, three asbestos-bearing zones were exposed in the topmost stratum of the lower member. A 6-inch serpentine band, immediately under the base of the algal member contained a total of 3 inches of fiber. This zone was stoped for a length of more than 100 feet. The zones at l½ and 3 feet lower usually contained short fiber and were discontinuous and unimportant.
>
> Other adits and stopes nearer to the point were mined through to the east side of the ridge. The major zone at the base of the algal member consisted of 2½ feet of serpentine containing up to 3 or 4 inches of soft, amber-color fiber.
>
> Several other adits and smaller stopes indicated decreasing mineralization to the south; the veins of the southernmost adit contain bands of bone bordered with short fiber.
>
> White Tail No. 2.--At this locality, the asbestos-bearing strata outcrop under the algal member about 80 feet below the top of the limestone cliffs and 60 feet above the underlying diabase. A northeast trending, 6-foot, vertical diabase dike crosscuts the limestone. Thin sills branch out from this dike and extend into the limestone for considerable distances. On the east side of the dike 2 adits connected by stoping opened the deposit to a depth of 115 feet. The deposit is localized near the dike and immediately under the base of the algal member in limestone warped by a thrust fault.
>
> The asbestos is distributed somewhat erratically in concentrations up to 3½ inches of fiber. The quality varies from soft to semi-soft and near the face of the stope appears to be fairly harsh.
>
> The Bureau of Mines explored the limestone block west of the dike in 1943. A thrust fault was encountered that raised the ore zone above drift level. Two raises were put up to the ore zone, and a few feet of

drifting was done on the ore zone from each raise, which exposed 3 fairly soft fiber veins approximately 1 foot apart. A little stoping has been done in one of these raises since that time.

During the Bureau project, the possibility of asbestos mineralization in the upper, detached limestone segment was investigated. An opencut exposed the favorable bed under the algal limestone; but serpentinization was poor, and only a little harsh fiber was noted.

Loey and Lena Prospect

According to Moore (1968, p. 51), the Loey and Lena prospect consists of a 62-acre tract in sec. 5, T. 5 N., R. 17 E. (Figure 6 and Figure 7). The property was located prior to 1928 and was worked in 1928-29 and then intermittently between 1935 and 1940. "By 1955 the deposit had been developed by three shallow cuts and two small stopes about 50 feet long and 20 feet wide" (Moore, 1968, p. 51).

Stewart (1955, p. 47) reports that asbestos occurs in two mineralized zones above a thick diabase sill. The upper zone is 8 to 10 inches thick and contains traces of veins of asbestos. The same author states that the lower zone contains one-half inch asbestos veins in a few places.

Roadside Mine (Cibecue Mining Co., Inc., Old Prochnow Property)

The Roadside mine property, in sec. 19, T. 5 N., R. 18 E. (Figure 6), apparently contains only limited quantities of fiber. Stewart (1955, p. 48-49) describes as harsh fibers all asbestos investigated on the property. He also describes the geology as being about the same as other asbestos occurrences on the reservation.

The mine workings consist of five short adits and two bench cuts.

Snake Hill Deposit

The Snake Hill deposit is in sec. 30, T. 5 N., R. 18 E. (Figure 6). Stewart (1955, p. 49-50) states:

> Steep cliffs of Mescal limestone lie above a diabase sill that forms the bottom 100 feet of the north canyon wall of Salt River at this point. The main adit, at an altitude of approximately 3,600 feet, is situated midway between two nearly parallel, north-northwest-trending, vertical faults that have dropped and tilted an 80-foot-wide block within the limestone strata. The east side of the block has dropped 25 feet, the west side only 10 feet. From the fault block east the limestone bedding is folded upward against a crosscutting discordance in the diabase. West of the block the diabase is concordant and relatively level.
>
> The fault block has been shattered by minor fault adjustments and bedding-plane

> slips. Asbestos mineralization is present for a few feet at the portal of the adit. The asbestos zone is 23 feet above the sill and 26 feet below the base of the algal member. A second serpentinized zone, barren of fiber is 5 feet lower in the section.

Underground workings are estimated to total about 350 feet. The fiber is described as soft and about 3 or 4 inches thick in a 12- to 15-inch serpentine zone.

Fiber King Mine (Salt Bank, River Side)

According to Stewart (1956, p. 25), the Fiber King property is in sec. 13, T. 5 N., R. 16 E. (Figure 6). The property produced asbestos intermittently from 1923 through 1951. The following description was taken from Stewart (1956, p. 25-28):

> In the central part of the property a relatively narrow ridge exposes more than 100 feet each of the lower and algal Mescal members. This limestone section is underlain and overlain by thick diabase sills. Asbestos-bearing zones outcrop at several places under the base of the algal limestone and in beds 100 feet lower and a few feet above the underlying sill. The major deposit is in this lower horizon on the southeast side of the hill near a discordance in the underlying diabase at an approximate altitude of 3,500 feet.

> The major deposit is localized adjacent to a discordant diabase structure that has a general trend of N. 20º W. The top of the underlying sill cuts up from the east, becomes concordant westward for about 30 feet and again rises, cutting off the favorable beds in that direction. The mineralized zone is in massive bedding about 5 feet above the concordant part of the structure. An adit has been driven N. 10º W. for 220 feet. Stopes carrying the ore zone on the back are opened for 25 feet west and to a maximum of 90 feet east of the adit.

> The crosscutting diabase that terminates the deposit to the west is exposed in a crosscut and in one corner of a back-filled stope, which probably is against or close to the diabase for the remaining length of the stope to the north. Near this contact the serpentinized zone is 18 to 24 inches thick and usually contains 2 inches of short fiber in numerous veinlets.

> The stopes on the east side of the adit have been worked to the commercial limit of the deposit. On the south side of the next canyon, about 400 feet north, asbestos is exposed for an outcrop length of 50 feet along a minor monoclinal structure. A 30-foot adit was driven S. 35º W. into this deposit. From 1½ to 2 inches of semisoft fiber was mined from a small side stop to a depth of 20 feet. The face of the adit is virtually barren. The zone is 5 feet above the concordant diabase sill.

Across the canyon 100 feet northeast a short adit was driven in a segment of limestone within a narrow trough like depression in the top of the sill. A zone containing up to 3 inches of harsh fiber was exposed, but this was virtually cut out by a break in the formation 15 feet from the portal.

Late in 1942 John A. Bacon prospected a deposit on the Victory claim about 2,000 feet southwest of the Fiber King deposits. At the surface there was 1 to 2 inches of soft and semisoft asbestos in an 8-inch serpentine zone about 5 feet above a concordant diabase sill An adit was driven N. 15º E. for 75 feet. Sixty feet from the portal the underlying diabase cut upward to the ore zone and terminated the deposit. A second adit 65 feet west was driven due north but encountered the same diabase roll 55 feet from the portal. The axis of the discordance was N. 70º E., or approximately parallel to the surface.

The fiber zone virtually pinched out in the adits 30 feet from each portal, where the limestone beds, which dip 8º to 10º at the surface, become almost horizontal. A small production, some of which was No. 1 Length, was made from a bench cut and near surface stopes.

This deposit is in a limestone section below the diabase sill that underlies the Fiber King workings. Because of the thinning of this sill southward, it is likely that these 2 deposits are in the same horizon, that is, in bedding 100 feet stratigraphically below the algal limestone.

Asbestos-bearing serpentine is exposed in a bench cut for an outcrop length of 50 feet N. 40º W. of and 100 feet higher than the Fiber King adit previously discussed. The mineralized zone occurs in beds 2½ feet below the base of the algal limestone and 30 feet above a discordance in the same diabase sill that underlies the main adit. Strong, premineral bedding-plane faulting along the algal base has formed a wedge of gouge thickening to the west. The strongest mineralization occurs near the apex of the wedge at the east end of the cut. An adit driven 50 feet N. 18º W. shows up to 1½ inches of fiber at the top and ½ inch at the bottom of a strong serpentine zone. The fiber is soft but short and becomes even shorter in a 10-foot, northeast-bearing crosscut. Apparently a small production was made, as the adit is wide.

Across the hill to the northeast 2 cuts about 100 feet apart prospect small lenses of fiber at the base of the algal limestone. A maximum of 1½ inches of asbestos, some of which is No. 2 grade, is exposed.

On the southeast face of the hill, about midway between the above-described occurrences, another opencut shows a full face of serpentinized material with only

> narrow fiber veinlets 8 inches, 2, 3, and 4 feet below the algal base.

Bluff Claims

According to Stewart (1956, p. 28), the Bluff Claims are in sec. 27, T. 5 N., R. 17 E. (Figure 6). It is apparently not known how much asbestos was produced from this property, but the author reports that the property was located in 1921 and yielded a small amount of asbestos in 1949-1959. Some material may also have been produced after 1954.

The geology and mineralization of the occurrence is substantially the same as at other deposits of the region. That is, the asbestos occurs in the lower Mescal Limestone that has been intruded by diabase sills. Stewart (1956, p. 29-30) reports:

> Considerable benching and opencut work have been conducted just south of the highway approximately 1 road mile upstream from the bridge. The limestone beds are wedged out at road level by a discordant diabase structure that dips northward.
>
> Near the top of this limestone wedge an asbestos-bearing serpentine zone has been exposed and partly mined out by opencut work. On the north side of the remaining limestone knob and 2 feet below diabase a 9-inch serpentine band contains nearly 4 inches of fairly harsh asbestos in $^{1}/_{16}$- to ¼-inch veinlets. About 50 feet southward, on the opposite side of the knob, the same zone, which here is 14 feet below the diabase, exposes nearly 2 inches of soft fiber, in shallow opencuts, some of which is No. 1 Length. This mineralization is about 175 feet above the top of the Dripping Spring quartzite and at an approximate altitude of 3,700 feet.
>
> The present operators (October 1944) are dozing a bench to another zone said to be 40 feet lower in the section. The outcrop of this zone was not seen by the writer because of dump material from the work above. During this work a lens of mineralization was uncovered about 15 feet below the upper zone. It contained up to 2 inches of harsh fiber but was of very limited extent.
>
> One-half mile southeast of the above-described work, on the west side of a ridge, minor asbestos-bearing zones occur in the limestone between two thick diabase sills. About midway along the ridge and a few feet below the upper sill, a shallow cut exposes 1½ inches of short fairly harsh fiber in a poorly serpentinized zone. This occurrence is 18 feet above a 10-foot sill that has been intruded in beds 50 feet above the underlying diabase.
>
> Farther south, where the limestone is only 30 feet thick between discordancies of both major sills, a 3-foot zone of serpentinized material contains several discontinuous and erratically disposed veinlets of soft asbestos. This zone, 5 feet above the underlying diabase contact, has been prospected by 3

bench cuts for a lateral distance of 80 feet. The fiber content is distributed in several veinlets, none of which is more than ½ inch thick.

Reserves

The quantity of asbestos remaining on the Fort Apache Reservation is unknown, but Moore (1968, p. 53-54) states that, "Considerable high-grade fiber remains in many of the deposits discussed." He further states that there are probably good deposits yet to be discovered.

According to Bureau of Mines commodity specialists (oral communication), the demand for asbestos fibers will continue and possibly increase over the next 20 or 25 years. Therefore, it is possible that a resurgence of the asbestos mining industry in Arizona and on the Fort Apache Reservation may occur.

Gypsum

Gypsum resources on the reservation are of two varieties, massive rock gypsum and selenite. Both have the same chemical formula ($CaSO_4$ $2H_2O$). Another variety of gypsum, alabaster, often occurs as massive gypsum, and may be present on the Indian land. Of the three varieties, rock gypsum has the greatest commercial potential. It is used to make plaster of paris, wallboard, and plaster. It is also used as a fertilizer and as a retarder in portland cement. Alabaster is often cut and polished for ornamental purposes.

All significant gypsum deposits on the reservation apparently are in the Permian Supai Formation. According to Moore (1968, p. 64), the gypsum beds may make up as much as 7 percent of the 1,300-foot thickness of the Supai. Moore also indicates that the gypsum occurs in three horizons in the Supai and that the upper zone has the greatest economic potential. The upper zone was investigated at several locations by personnel of the Arizona Bureau of Mines, and Moore (1968, p. 65) states that an exposure in sec. 33, T. 9 N., R. 21 E., is the most favorable locality on the reservation for exploration and possible mining. The zone was measured about 1 mile west of the exposure mentioned above and found to contain 40 feet of gypsum including two units, 16 and 11 feet thick, separated by 2 to 3 feet of siltstone. Investigation of other exposures in the upper zone included one in sec. 16, T. 7 N., R. 22 E., where one bed measured 30 feet thick, although it is in a steep slope area that would make surface mining difficult or impossible. At another site, the upper zone measured only 3 feet thick and at another the zone was 80 feet thick, but the thickness of individual beds is not given (Moore, 1968, p. 66).

The lower zone also was investigated by Moore who reports that this zone consists of "...1 to 3 beds ranging in thickness from 1 to 12 feet each." Most exposures investigated in this zone, however, were believed not to be amenable to surface mining. Nevertheless, one exposure in sec. 8, T. 5 N., R. 21 E., Moore (1968, p. 66) was reported to contain benches of gypsum 10 feet thick. The area is near highway 60 and could be mined by surface methods. Moore (1968, p. 67) states that a third localized gypsum zone could not be mined by open-pit methods.

Finely crystallized gypsum (selenite) generally is not a commercial commodity unless sold in minor quantities as a curio. Blake (1904, p. 101), however, reports that selenite is found in three locations on the reservation in plates of considerable size and in such quantity that it was once proposed for use as a building stone for housing tribal members.

Apparently gypsum occurs on Fort Apache land in enormous quantities, and some of it may be amenable to surface mining methods. However, owing to remoteness of markets and vast quantities of the material in locations closer to both transportation and markets, it is unlikely that it can be economically mined within the foreseeable future.

Clay

Clay has been produced commercially from one deposit on the reservation, and it occurs in several other places. According to BIA records, Building Products Co. of Phoenix leased 80 acres in NE¼ sec. 4, T. 6 N., R. 19 E., (Figure 6) in 1971. The company produced 4,775 tons of clay during 1971-1972 for clay-pipe manufacture at a plant in Phoenix. The clay from this deposit was blended with clays produced elsewhere. Clay was not produced after 1972, and the lease was canceled in 1974. Royalty was $1.35 per ton with a $1,000.00 guarantee plus a $1.00 per acre royalty.

Little has been published concerning clays in Arizona, but Moore (1968, p. 72-73) sampled several deposits on the reservation and did some testing. He collected 19 samples from 14 locations and classified 13 of them good for such purposes as common brick, whiteware and ceramic ware. According to Moore (1968, p. 72), many of the samples showed that the clay was high-purity kaolinite.

Based on work by Moore, it is evident that the clay deposits on the reservation contain a large quantity of relatively high quality clay. However, because of the distance from markets, it is unlikely that large quantities of clay will be mined in the near future. Notwithstanding, it is possible that small quantities of clay may be mined from time to time depending on market demands and the availability of clay from other areas.

Limestone

Limestone, suitable for most purposes, is exposed at several localities on the reservation. Moore (1968, p. 67-71) investigated several deposits and concluded that, "Large reserves of limestone occur on the Fort Apache Indian Reservation, particularly in the Redwall, Naco and Kaibab Formations. Analyses indicate that deposits suitable for the production of lime and cement are easily accessible." However, some of the better quality material that could be used for chemical-grade material is, according to Moore, remote from markets (sec. 20, T. 5 N., R. 18 E.) and cannot be considered commercially competitive. Nevertheless, some Kaibab Limestone that he sampled in SE¼ sec. 23, T. 8 N., R. 2 E., is probably suitable for most purposes and is amenable to surface mining methods that would require little or no overburden removal.

According to Moore (1968, p. 67), another limestone deposit contains more than 6 million cubic yards. The material, in secs. 6, 7, T. 7 N., R.

20 E., is quite accessible and would be suitable for cement production.

Large quantities of high-quality limestone occur on Fort Apache land. Although some of it is close to roads and would be amenable to strip-mining methods, it is remote from existing markets. It is unlikely that limestone on the reservation can be economically developed in the near future. If a need develops, much of the limestone in the area could be crushed for road metal, railroad ballast, aggregate, or other uses.

Salt

Salt has been known on the reservation since about 1870. Numerous salt springs are located near the Salt River where the river emerges from the plateau region (Reagan, 1911, p. 1,274). According to Reagan, salt was produced by evaporation during the 1870's for use in producing silver from ores mined at McMillanville. Apparently the silver mines operated only a short time and salt production ceased, and no attempt has been made to produce salt since that time. According to Moore (1968, p. 54), the source of the salt is not known.

The quantity of salt in the deposit is not known. Moore (1968, p. 54) reports that the springs supply 50,000 tons of salt to the Salt River per year. Although it is unlikely that salt could be produced commercially from these springs, it might be possible, with a minimum capital investment, to produce salt for livestock.

Sand and Gravel

Sand and gravel occur on the reservation in enormous quantities. Many deposits have been mined to a limited extent (Figure 6), mostly by the Arizona Highway Department. Table 3 is a partial list of sand and gravel pits on the reservation. Moore (1968, p. 15) states, "Thick accumulations of alluvial material can be found in every major stream valley in the area." Moore also indicates that large deposits of sand and gravel are present at some of the higher elevations near Cibecue and Spring Ridge.

According to BIA personnel, sand and gravel leases generally run for a period of 5 years. Royalties range up to $0.35 per ton with apparently no minimum fees. Most of the pits are active only intermittently, and many are abandoned after brief periods of operation.

TABLE 3

Sand and Gravel Pits on the Fort Apache Indian Reservation*

Producer	Location	Acres
State of Arizona	NW¼ sec 24, NE¼ sec 23, SE¼ sec 14, T 7 N, R 19 E	33.3
"	sec 29, T 6 N, R 23 E	22.5
"	NE¼ sec 29, T 7 N, R 23 E	11.0
"	NE¼ sec 5, T 5 N, R 23 E	28.0
"	sec 24, 25, T 7 N, R 19 E	8.8
"	secs 21, 22, T 4½ N, R 22 E	55.6
"	T 6 N, R 20 E	42.8
"	NW¼ sec 27, T 9 N, R 21 E	16.9
"	SE¼ sec 13, T 5 N, R 22 E	21.0
"	sec 24, 25, T 7 N, R 19 E	8.8
"	N½ sec 24, T 7 N, R 19 E	11.5
"	sec 2, T 3 N, R 19 E	42.5
"	SE¼ sec 21, T 5 N, R 21 E	8.0
"	NE¼ sec 29, SW¼ sec 28, T 7 N, R 23 E	36.5
"	NE¼ sec 5, T 6 N, R 23 E	4.5
"	SW¼ sec 28, SE¼ sec 29, T 7 N, R 23 E	80.0
"	SE¼ sec 16, T 7 N, R 23 E	5.0
"	NW¼ sec 7, T 8 N, R 21 E	10.0
"	NE¼ sec 35, T 10 N, R 21 E	15.0
"	NW¼ sec 11, T 9 N, R 21 E	10.0
"	NE¼ sec 22, T 9 N, R 21 E	17.5
"	NE¼ sec 27, T 9 N, R 21 E	7.5
"	NW¼ sec 27, T 9 N, R 21 E	7.5
"	SE¼ sec 33, T 9 N, R 21 E	15.0
"	NW¼ sec 22, T 9 N, R 21 E	17.5
"	SW¼ sec 34, T 9 N, R 21 E	15.0
"	NW¼ sec 13, T 8 N, R 20 E	15.0
"	NW¼ sec 23, SW¼ sec 14, T 8 N, R 20 E	12.5
"	SE¼ sec 14, NE¼ sec 23, T 7 N, R 19 E	120.0
"	SE¼ sec 7, T 7 N, R 27 E	15.0

*Source BIA records. This may not be a complete list as not all records were available. Moreover, locations may not fully coincide with those pits shown on Figure 6.

Specialty Sand

Some sands, because of their chemical and/or physical properties, have uses for which most deposits cannot be used. Such sands are used as foundry sand, for glass manufacture, as filters, and for plaster, which require rigid specifications. Moore (1968, p. 74-75) describes several sand deposits that may meet specifications for some specialty uses (Figure 6). A deposit in sec.27, T. 8 N., R. 20 E., contains more than 98 percent silica and less than 0.1 percent iron, and may meet requirements for glass manufacture. Another deposit in sec. 24, T. 8 N., R. 20 E., is apparently a sandstone in which the individual quartz grains are cemented together by kaolin clay. Moore (1968, p. 75) indicates that the silica can be separated from the clay in the laboratory. If the same separation could be made on a commercial scale, it is possible that two marketable products (silica sand and kaolin) could be produced. Moore collected two samples from a deposit in sec. 10, T. 8 N., R. 21 E., characterized as high-grade silica. He does not however give the chemical composition. Moore also collected a sample from a deposit in sec. 2, T. 9 N., R. 20 E., that he describes as a white friable sandstone containing more than 98 percent silica.

Although Moore's work seems to indicate that specialty sands are present within the reservation, it would require a systematic sampling program and detailed analyses to prove commercial reserves of high-silica sand.

Scoria (Cinders)

Scoria (cinders) occurs in the eastern part of the Fort Apache Reservation in enormous quantities. The material currently is mined and used mostly for road metal and railroad ballast. Current production is at the McNary cinder pit in sec. 25, T. 8 N., R. 23 E. (Figure 6), an area where permits have been awarded to several companies to mine cinders. Production by each company is intermittent and apparently ranges from very small to somewhat larger quantities. The producing companies pay a royalty to the tribe of $0.35 per cubic yard. Probably the biggest producer to date was the Apache Railway Co., which produced 150,802 cubic yards from the McNary pit between 1970 and 1974. Royalty at that time was $0.10 per cubic yard. Southwest Forest Industries produced 14,736 cubic yards of cinders from a pit in NW¼ sec. 20, T. 8 N., R. 2 E., in 1977-1978. Other pits are in sec. 22, T. 8 N., R. 23 E., and NE¼ sec. 3, T. 7 N., R. 23 E.

Scoria is present in huge quantities on the reservation and is sufficient to last indefinitely.

Stone

In addition to the limestone mentioned above, several types of stone are present on the reservation. The list includes sandstone, travertine, serpentine basalt, and perhaps marble. Stone on the reservation is remote from markets and access is often difficult. Nevertheless, Ultra Marble Inc. acquired a lease on 680 acres of land near the Salt River in 1963. The company paid the tribe $6,800.00 advance royalty and planned to produce serpentine and marble, but it went out of business before production could begin.

Most of the various types of stone could be produced as dimension (building) stone or could be crushed and used for road metal, riprap, or for decorative purposes. However, because most types of stone occurring on the reservation are found elsewhere in vast quantities, it is unlikely that stone from deposits on the reservation will be produced in significant quantities in the near future.

Turquoise and Other Decorative Material

Turquoise and several other varieties of decorative minerals occur on the reservation that might be suitable for cutting, polishing, carving, etc. Among those listed by Moore (1968, p. 77, 83) are banded gypsum, Mexican onyx, travertine, onyx marble, jasper, crystalline barite and barite concretions, quartz geodes, and red silicified fossils.

Turquoise has been noted and, according to Moore (1968, p. 54), was produced by aboriginal residents of the area. The deposit is about 1.1 miles northeast of the confluence of Canyon Creek and the Salt River. Workings are described as two shallow quarries about 1,000 feet apart. The turquoise occurs along with the uranium mineral metatorbernite as coatings and blebs along bedding planes and in fractures in the Dripping Spring Quartzite. Moore suggests (1968, p. 55) that more turquoise deposits might be located by using radiometric methods, such as a Geiger counter, to detect the radioactivity resulting from the metatorbernite in the occurrences.

It is most unlikely that a large business enterprise could be sustained from the production of either turquoise or the other decorative minerals found on the reservation. It is possible, however, that one or more small businesses could be started to collect, cut, and polish the materials for sale to tourists and people visiting the ski area.

MAP COVERAGE

The USGS has published 7.5- and 15-minute topographic quadrangle maps covering the entire reservation (Figure 8). Applicable maps in these series are:

<u>7.5-Minute Maps</u>

Alchesay Flat	Lakeside
Bear Ridge	Limestone Canyon
Beckers	Limestone Canyon North
Bonito Prairie	Long Tom Canyon
Bonito Rock	Marshall
Boundary Butte	Maverick
Canyon Day	Maverick SW
Carrizo	McNary
Carrizo SE	Mt Ord
Cedar Creek	Nantanes Mtns NE
Chediski Peak	Oak Creek Ranch
Cibecue Peak	Odart Mtn
Cone Butte	Pepper Canyon
Corn Creek	Popcorn Canyon
Elwood	Red Top Mtn
Forks Butte	Round Top
Freezeout Mtn	Sawbuck Mtn
Georges Butte	Sponseller Mtn
Greens Peak	Spotted Mtn
Hawley Lake	Velasquez
Hawley Lake West	West Poker Mtn
Haystack Butte	White River
Horseshoe Cienega	Whiting Knoll

<u>15-Minute Maps</u>

Blue House Mt	McFadden Peak
Chediski Peak	McNary
Cibecue	Rockinstraw Mtn
Clay Springs	Woods Canyon
Heber	Young

The USGS has also published a "Geologic Map of Arizona." The same agency has also published a "Salt River Arizona Map" on a scale of 1:31,680 that covers the Salt, Black, and White Rivers.

In addition to the topographic and geologic maps listed, the USGS has published a base map of the state of Arizona. All listed maps may be ordered from the U.S. Geological Survey, Branch of Distribution, Central Region, Box 2586, Denver, Colo. 80225. The USGS also has published a topographic map of the Fort Apache Indian Reservation in two parts, at a scale of 1:100,000. The maps may be obtained from the White Mountain Tribe at White River, Ariz.

Another useful source of maps is the Bureau of Land Management, which has available land status master title plats, accompanied by an historical index. Both the plats and historical indexes may be ordered from the U.S. Bureau of Land Management, 2400 Valley Bank Center, Phoenix, Ariz. 85073; township and range should be designated.

The Arizona Department of Transportation publishes county road maps of the reservation. The Apache, Navajo, and Gila County maps are available. Requests should be addressed to the Arizona Department of Transportation, Engineering Records Group, 206 S. 17th Ave., Phoenix, Ariz. 85007. The Arizona Bureau of Mines publishes a series of geologic and mineral maps that may be purchased from the Arizona Bureau of Mines, 845 North Park Ave., Tucson, Ariz. 85719. The Arizona Department of Natural Resources in Phoenix may also have pertinent map information.

Aerial photographic coverage of the reservation is available from the U.S. Geological Survey NCIC-W, 345 Middlefield Road, Menlo Park, Calif. 94025. Satellite imagery can be obtained from the U.S. Geological Survey, EROS Data Center, Sioux Falls, S. Dak. 57198.

RECOMMENDATIONS

The general geology of the Fort Apache Indian Reservation and the mineral commodities present are reasonably well known. Future investigations should concentrate on detailed field studies aimed at outlining areas of mineral potential and at quantifying the resources available. These studies would provide background information useful in evaluating resources for local industries or for possible uses far from the reservation. Detailed examinations would then be required to determine more exactly the size, uniformity, depth of burial, grade, or other factors of importance in the production of individual commodities under favorable market conditions.

REFERENCES

Allen, M. A. and Butler, G. M., 1921, Asbestos: Arizona Bureau of Mines Bulletin 113, 31 p.

Alto, B. R., Lee, W. H., and Throckmorton, Mike, 1979, Lands valuable for geothermal resources: U. S. Geological Survey Map, scale 1:500,000.

Andrews, D. A., Hendricks, T. A., and Huddle, J. W., 1947, Analysis of Arizona, California, Idaho, Nevada, and Oregon coals. U. S. Bureau of Mines Technical Paper 696, p. 1-3, 32-33.

Anthony, J. W., Wilson, E. P., and Moore, R. T., 1953, Bibliography of the geology and mineral resources of Arizona, 1939-1952: Arizona Bureau of Mines Bulletin 161, 62 p.

Arizona Bureau of Mines and Mineral Resources, 1969, Mineral and Water Resources of Arizona: Bulletin 180, 638 p.

Averitt, Paul, and O'Sullivan, R. B., 1969, Mineral fuels and associated resources--Coal, in Mineral and water resources of Arizona: Arizona Bureau of Mines Bulletin 180, p. 59-77.

Blake, W. P., 1904, Gypsum deposits in Arizona: U. S. Geological Survey Bulletin 223, p. 100-101.

Bromfield, C. S., and Shride, A. F., 1956, Mineral resources of the San Carlos Indian Reservation, Arizona: U. S. Geological Survey Bulletin 1027-N, p. 613-691.

Burchard, E. F., 1930, Iron ore on Canyon Creek, Fort Apache Indian Reservation, Arizona: U. S. Geological Survey Bulletin 821-C, p. 51-75.

Cox, D. P., Schmidt, R. G., Vine, J. D., Kirkemo, Harold, Tourtelot, E. B., and Fleischer, Michael, 1973, Copper, in Brobst, D. A., and Pratt, W. P., eds., United States mineral resources: U. S. Geological Survey Professional Paper 820, p. 163-190.

Cuffney, R. G., 1977, Geology of the White Ledges area, Gila County, Arizona: Golden, Colorado School of Mines, M. S. thesis, 141 p.

Darton, N. H., 1925, A resume of Arizona Geology: Arizona Bureau of Mines Bulletin 119, 298 p.

Elston, D. P., and Bressler, S. L., 1978, Stratigraphic and paleomagnetic relations between basal Cambrian and Devonian strata in central Arizona, in Burt, D. M., and Pewe, T. L., eds., Geology of central Arizona: Arizona Bureau of Geology and Mineral Technology Special Paper 2, p. 138-150.

Farnham, L. L., Stewart, L. A., and DeLong, C. W., 1961, Manganese deposits of eastern Arizona: U. S. Bureau of Mines Information Circular 7990, 178 p.

Feth, J. H., 1954, Preliminary report of investigations of springs in the Mogollon Rim region, Arizona: U. S. Geological Survey Open-File Report 317, 77 p.

Feth, J. H., and Hem, J. D., 1963, Reconnaissance of headwater springs in the Gila River drainage basin, Arizona: U. S. Geological Survey Water Supply Paper 1619-H, 54 p.

Finnell, T. L., 1962, Recurrent movement on the Canyon Creek fault, Navajo County, Arizona, in Geological Survey Research 1972: U. S. Geological Survey Professional Paper 450-D, p. 80-82.

____,1966a, Geologic map of Chediski Peak quadrangle, Navajo County, Arizona: U. S. Geological Survey Geologic Quadrangle Map GQ-544, scale 1:62,500.

____,1966b, Geologic map of Cibecue quadrangle, Navajo County, Arizona: U. S. Geological Survey Geologic Quadrangle Map GQ-545, scale 1:62,500.

Finnell, T. L., Bowles, C. G., and Soule, J. H., 1967, Mineral resources of the Mount Baldy Primitive Area, Arizona: U. S. Geological Survey Bulletin 1230-H, 14 p.

Galbraith, F. W., 1947, Minerals of Arizona: Arizona Bureau of Mines Bulletin 153, 101 p.

Gilbert, G. K., 1875, Report on the geology of portions of New Mexico and Arizona: U. S. Geological and Geographical Surveys West of the 100th Meridian (Wheeler), v. 3, pt. 5, p. 503-567.

Granger, H. C., and Raup, R. B., 1969a, Detailed descriptions of uranium-bearing deposits in the Dripping Spring Quartzite, Gila County, Arizona: U. S. Geological Survey Open-File Report 1202, 145 p.

Granger, H. C., and Raup, R. B., 1969b, Geology of uranium deposits in the Dripping Spring Quartzite, Gila County, Arizona: U. S. Geological Survey Professional Paper 595, 108 p.

Haigler, L. B., and Brook, C., 1978, Lands valuable for coal, Arizona: U. S. Geological Survey Map, scale 1:500,000.

Haigler, L. B., and Miller, Sue, 1962, Sodium and potassium land classification map: U. S. Geological Survey Map, scale 1:500,000.

Haman, W. R., Sr., Stone, C., and Witcher, J. C., 1978, Geothermal Energy Resources of Arizona: Arizona Bureau of Geology and Mineral Technology, Geothermal Map No. 1, scale 1:1,000,000.

Harrer, C. M., 1964, Reconnaissance of iron resources in Arizona: U. S. Bureau of Mines Information Circular 8236, 204 p.

Haury, E. W., 1934, The Canyon Creek ruins and cliff dwellings of the Sierra Ancha: Globe, Ariz., Medallion Paper.

Huddle, J. W., and Dobrovolny, Ernest, 1945, Late Paleozoic stratigraphy of central and northeastern Arizona: U. S. Geological Survey Oil and Gas Investigations Preliminary Chart 10.

____,1952, Devonian and Mississippian rocks of central Arizona: U. S. Geological Survey Professional Paper 233-D, p. 67-112.

Livingston, D. E., 1969, Geochronology of older Precambrian rocks in Gila County, Arizona: Tucson, University of Arizona, Ph.D. thesis, 216 p.

Livingston, D. E., and Damon, P. E., 1968, The ages of stratified rock sequences in central Arizona and northern Sonora: Canadian Journal of Earth Sciences, v. 5, p. 763-772.

Luedke, R. G., and Smith, R. G., 1978, Map showing distribution, composition, and age of Late Cenozoic volcanic centers in Arizona and New Mexico: U. S. Geological Survey Miscellaneous Investigations Series Map I-1091-A, scale 1:100,000.

Marvine, A. R., 1875, Report on the geology of route from St. George, Utah, to Gila River, Arizona: U. S. Geological and Geographical Surveys West of the 100th Meridian (Wheeler), v. 3, pt. 2, p. 189-225.

McKay, E. J., 1972, Geologic map of the Show Low quadrangle, Navajo County, Arizona: U. S. Geological Survey Geologic Quadrangle Map GQ-973, scale 1:62,500.

Melhase, John, 1925, Asbestos deposits of Arizona: Engineering and Mining Journal, v. 120, No. 21, p. 804-810.

Merrill, R. K., and Pewe, T. L., 1971, The Sheep Crossing Formation: a new late Cenozoic epiclastic formation in east-central Arizona: Journal of the Arizona Academy of Sciences, v. 6, p. 226-229.

____,1977, Late Cenozoic geology of the White Mountains, Arizona: Arizona Bureau of Geology and Mineral Technology Special Paper 1, 65 p.

Moore, R. T., 1968, Mineral deposits of the Fort Apache Indian Reservation, Arizona: Arizona Bureau of Mines Bulletin 177, 84 p.

Moore, R. T., and Wilson, E. D., 1965, Bibliography of the geology and mineral resources of Arizona, 1848-1964: Arizona Bureau of Mines Bulletin 173, 321 p.

Otton, J. K., Light, T. D., Shride, A. F., Bergquist, J. R., Wrucke, C. T., Theobald, P. K., Duval, J. S., and Wilson, D. M., 1980, Mineral resources of the Sierra Ancha Wilderness and Salome Study Area, Gila County, Arizona: U. S. Geological Survey Miscellaneous Investigations Map MF-1162H.

Peirce, H. W., 1967, Geologic Guidebook 2 - Highways of Arizona, Arizona Highways 77 and 177: Arizona Bureau of Mines and Mineral Resources Bulletin 176, 73 p.

Peirce, H. W., and Gerrard, T. A., 1966, Evaporite deposits of the Permian Holbrook Basin, Arizona, in Rau, J. L., ed., Second symposium on salt: Northern Ohio Geological Society, v. 1, p. 1-10.

Peirce, H. W., Jones, Nile, and Rogers, Ralph, 1977, A survey of uranium favorability of Paleozoic rocks in the Mogollon Rim and Slope region east central Arizona: Arizona Bureau of Geology and Mineral Technology Circular 19, 59 p.

Peirce, H. W., Keith, S. B., and Wilt, J. C., 1970, Coal, oil, natural gas, helium, and uranium in Arizona: Arizona Bureau of Mines Bulletin 182, p. 34-35, 128, 136-140.

Peirce, W. L., Shafiqullah, M., and Damon, P. E., 1978, Pre-Pliocene Tertiary erosion, deposition, faulting, and volcanism, southern boundary of the Colorado Plateau, Arizona [abs.]: Geological Society of America, Abstracts with Programs, v. 10, no. 3, p. 141.

Ransome, F. L., 1903, Geology of the Globe copper district, Arizona: U. S. Geological Survey Professional Paper 12, 168 p.

____,1917, Some Paleozoic sections in Arizona and their correlation: U. S. Geological Survey Professional Paper 98-K, p. 133-166.

Ratte, J. C., Landis, E. R., Gaskill, D. L., and Raabe, R. G., 1969, Mineral resources of the Blue Range Primitive Area, Greenlee County, Arizona, and Catron County, New Mexico: U. S. Geological Survey Bulletin 1261-E, 91 p.

Reagan, A. B., 1903, Geology of the Fort Apache region in Arizona: American Geologist, v. 32, p. 267-308.

____,1911, Mineral resources of Ft. Apache Region, Arizona. Mining and Engineering World, v. 34, No. 3, p. 1274.

____,1932, Geological notes on the Fort Apache Region, Arizona: Kansas Academy of Sciences Transactions, v. 35, p. 260-273.

Reeside, J. B. Jr., 1944, Maps showing thickness and general character of the Cretaceous deposits in the Western Interior of the United States: U. S. Geological Survey Oil and Gas Investigations Preliminary Map 10, 1 sheet, no scale given.

Rubel, A. C., 1916, Coal in Arizona: Arizona Bureau of Mines Bulletin 17, p 10.

Shride, A. F., 1967, Younger Precambrian geology in southern Arizona: U. S. Geological Survey Professional Paper 566, 89 p.

_____,1969, Asbestos, in Mineral and water resources of Arizona: Arizona Bureau of Mines Bulletin 180, p. 303-311.

Silver, L. T., 1960, Age determinations on Precambrian diabase differentiates in the Sierra Ancha, Gila County, Arizona: Geological Society of Arizona Bulletin, v. 71, 12, p. 1973-1974.

____,1963, The use of cogenetic uranium-lead isotope systems in zircons in geochronology, in Radioactive dating; proceedings of the Symposium on Radioactive dating, Athens, 1962: Vienna, International Atomic Energy Agency, p. 279-287.

____,1964, Mazatzal orogeny and tectonic episodicity [abs.]: Geological Society of America Special Paper 82, p. 185-186.

____,1969, Precambrian batholiths of Arizona [abs.]: Geological Society of America Special Paper 121, p. 558-559.

Sirrine, G. K., 1958, Geology of the Springerville-St. Johns area, Apache County, Arizona: Austin, University of Texas, Ph.D. thesis, 193 p.

Stewart, L. A., 1947, Apache iron deposit, Navajo County, Arizona: U. S. Bureau of Mines Report of Investigations 4093, 88 p.

____,1955, Chrysotile-asbestos deposits of Arizona: U. S. Bureau of Mines Information Circular 7706, 124 p.

____,1956, Chrysotile asbestos deposits of Arizona: U. S. Bureau of Mines Information Circular 7745 (supplement to Information Circular 7706), 41 p.

Stewart, L. A., and Haury, P. S., 1947, Arizona asbestos deposits, Gila County, Arizona: U. S. Bureau of Mines Report of Investigations 4100, 28 p.

Stipp, T. F., 1960, Lands valuable for oil and gas, Arizona: U. S. Geological Survey Map, 1 sheet, scale 1:500,000.

Teichert, Curt, 1965, Devonian rocks and paleogeography of central Arizona: U. S. Geological Survey Professional Paper 464, 181 p.

U. S. Department of Commerce, 1970, U. S. Census of population for Arizona: p. 46-11 through p. 4-10

____,1974, Federal and state Indian Reservations and Indian Trust Areas: p. 46-48.

Veatch, A. C., 1911, Coal deposits near Pinedale, Navajo County, Arizona: U. S. Geological Survey Bulletin 431, p. 239-242.

Wilson, E. D., 1928, Asbestos deposits of Arizona, with an introduction on Asbestos minerals by G. M. Butler: Arizona Bureau of Mines Bulletin 126, 199 p.

____,1939, Bibliography of the geology and mineral resources of Arizona: Arizona Bureau of Mines Geological Series 13, Bulletin 146, 164 p.

____,1962, A resume of the geology of Arizona: Arizona Bureau of Mines Bulletin 171, 140 p.

____,1965, Guidebook 1 - Highways of Arizona, U. S. Highway 666: Arizona Bureau of Mines Bulletin 174, 68 p.

____,1971, A resume of the geology of Arizona: Arizona Bureau of Mines Bulletin 171, 140 p.

Wilson, E. D., Moore, R. T., and Peirce, W. L., 1959, Geologic map of Gila County, Arizona: Arizona Bureau of Mines, scale 1:375,000.

Winters, S. S., 1963, Supai Formation (Permian) of eastern Arizona: Geological Society of America Memoir 89, 99 p.

Wrucke, C. T., 1961, Paleozoic and Cenozoic rocks in the Alpine-Nutrioso area, Apache County, Arizona: U. S. Geological Survey Bulletin 1121-H, 26 p.

Click back button (<<) on toolbar to return to text

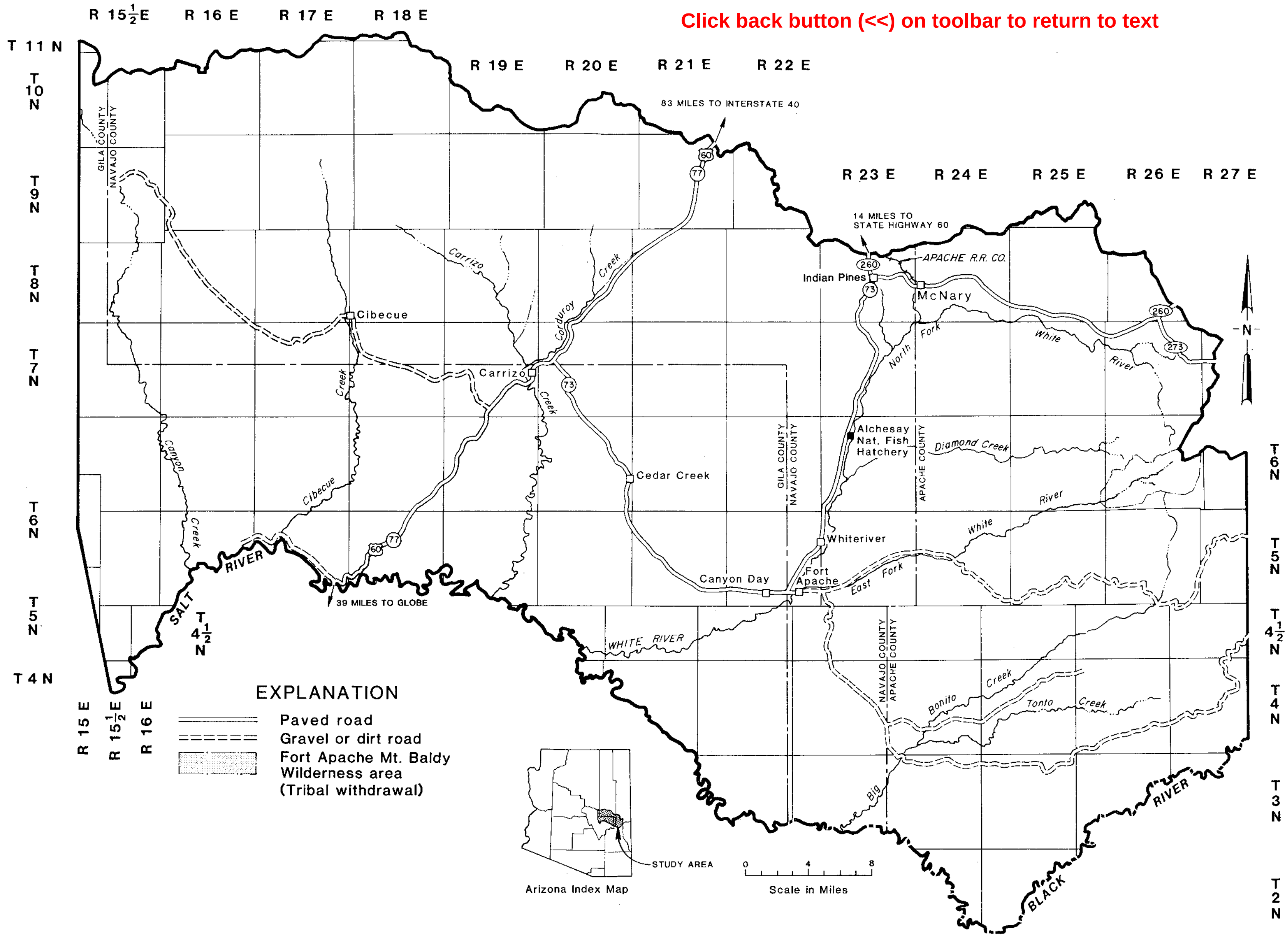

Figure 1. Map of the Fort Apache Indian Reservation, Apache, Gila, and Navajo Counties, Arizona.

Click back button (<<) on toolbar to return to text

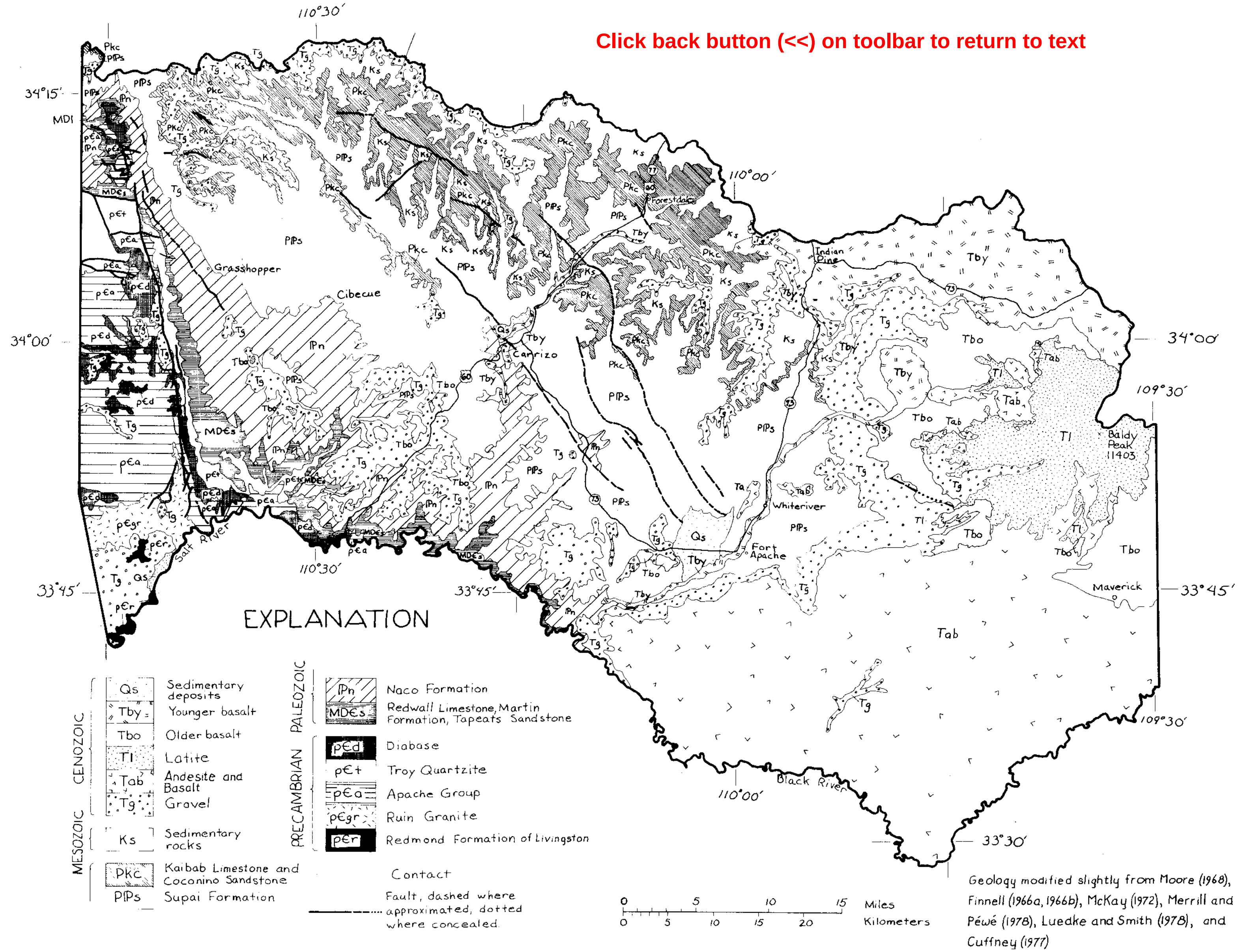

Figure 2. Generalized geologic map of the Fort Apache Indian Reservation, Arizona.

Click back button (<<) on toolbar to return to text

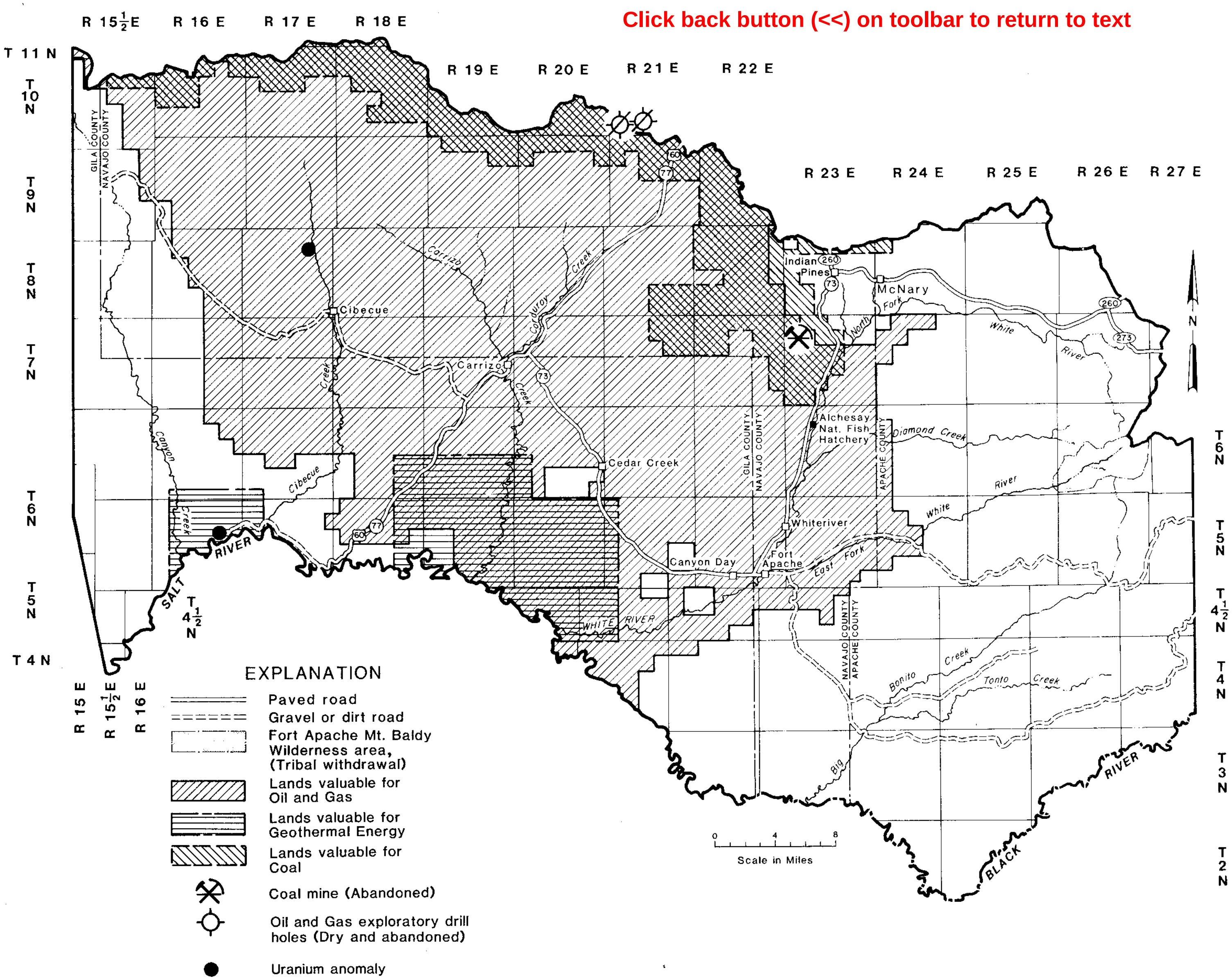

Figure 3. Map of the fuel resources of the Fort Apache Indian Reservation.

Click back button (<<) on toolbar to return to text

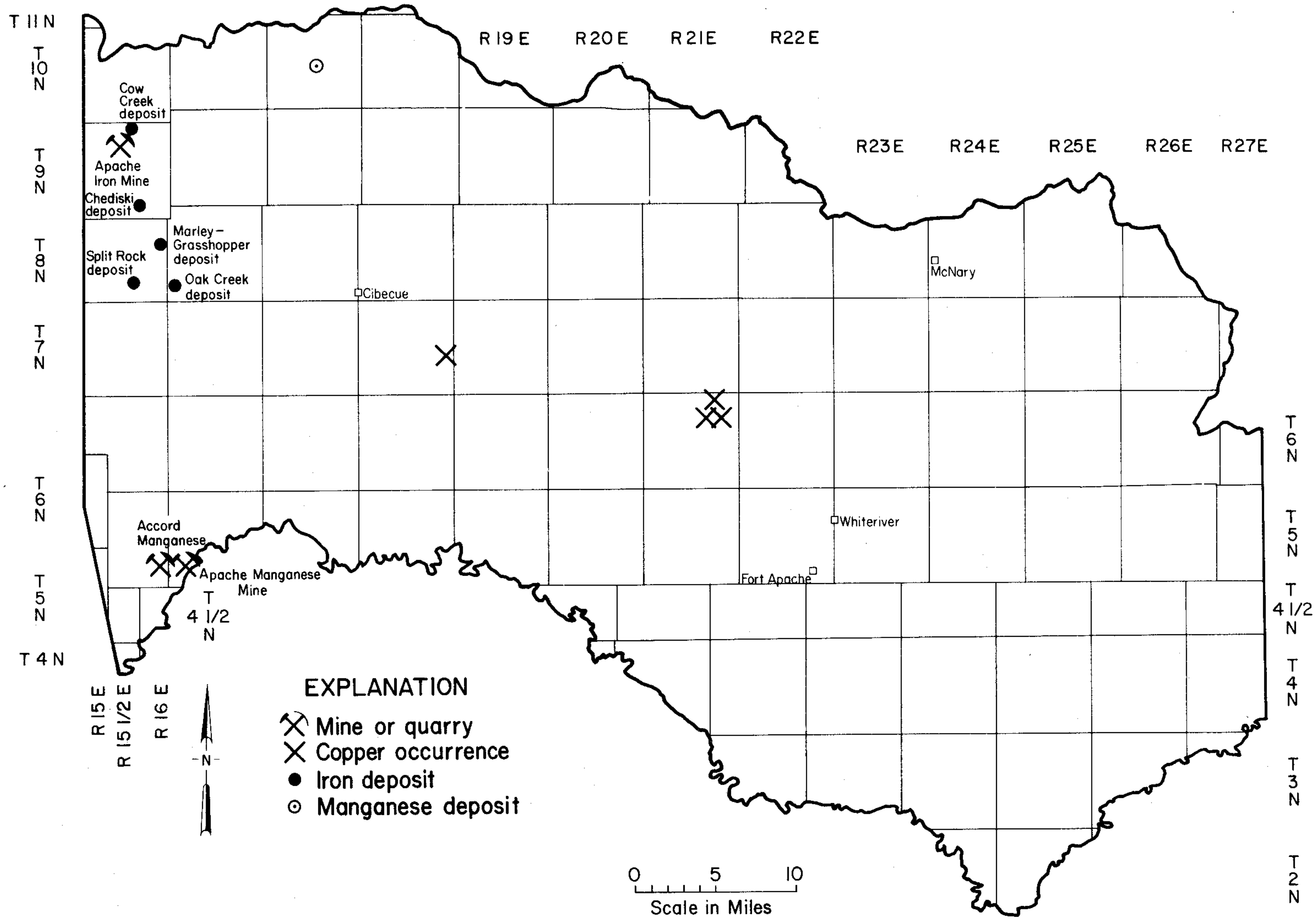

Figure 4. Map of the metalllic mineral resources of the Fort Apache Indian Reservation.

Click back button (<<) on toolbar to return to text

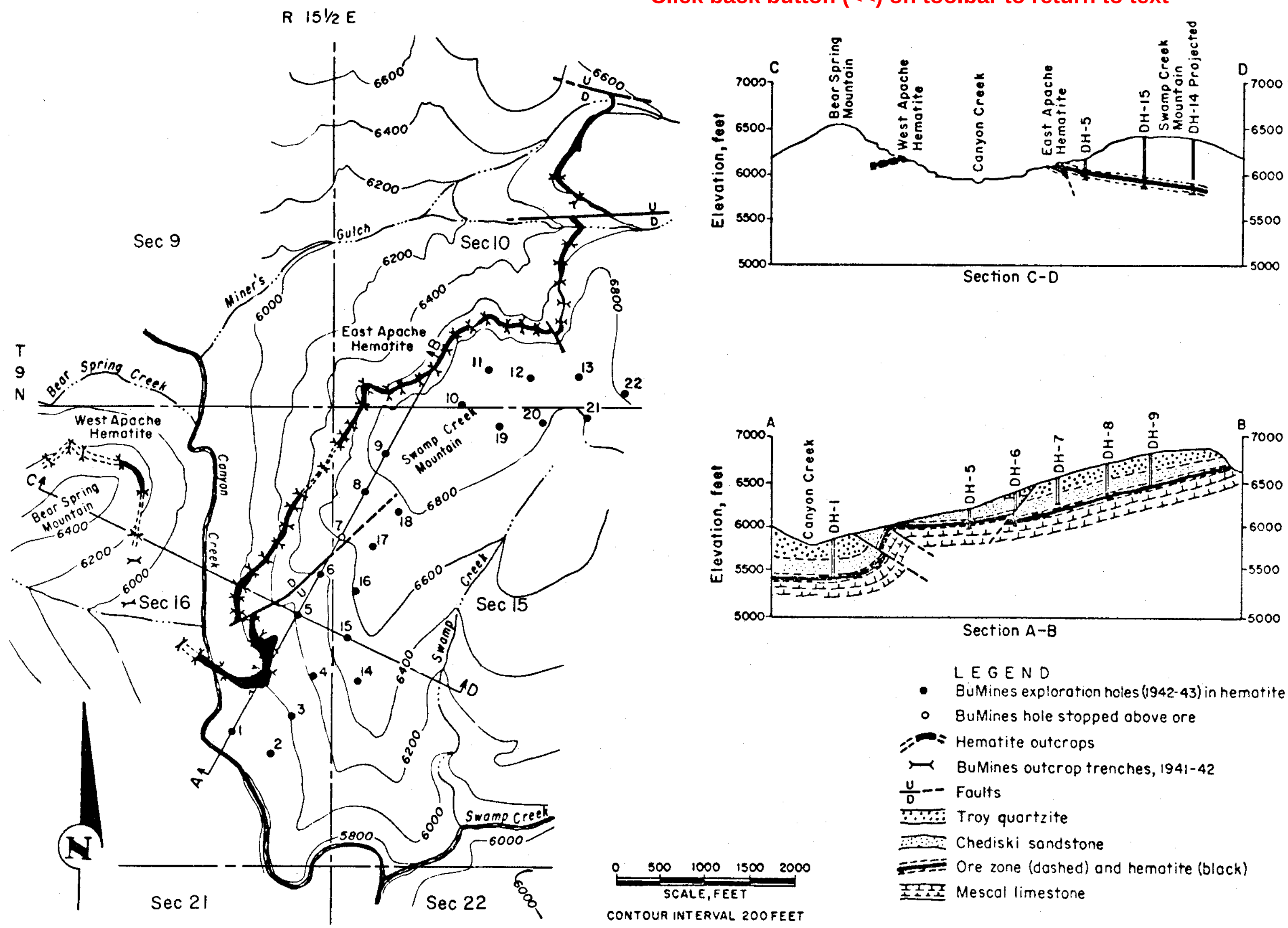

Figure 5. Map of Apache hematite deposits, Fort Apache Indian Reservation (adapted from Harrer, 1964, p. 75).

Click back button (<<) on toolbar to return to text

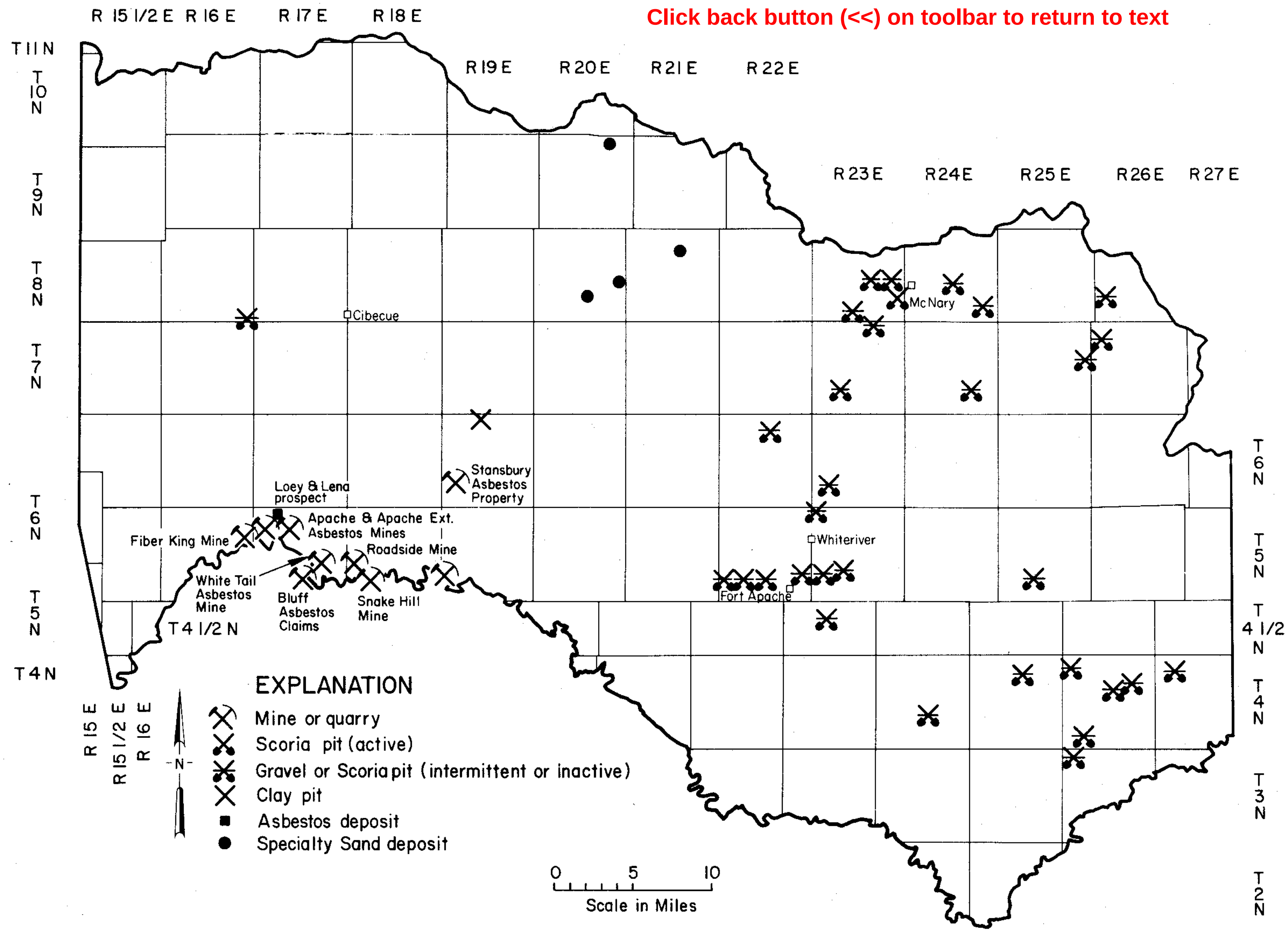

Figure 6. Map of the nonmetallic mineral deposits on the Fort Apache Indian Reservation.

Click back button (<<) on toolbar to return to text

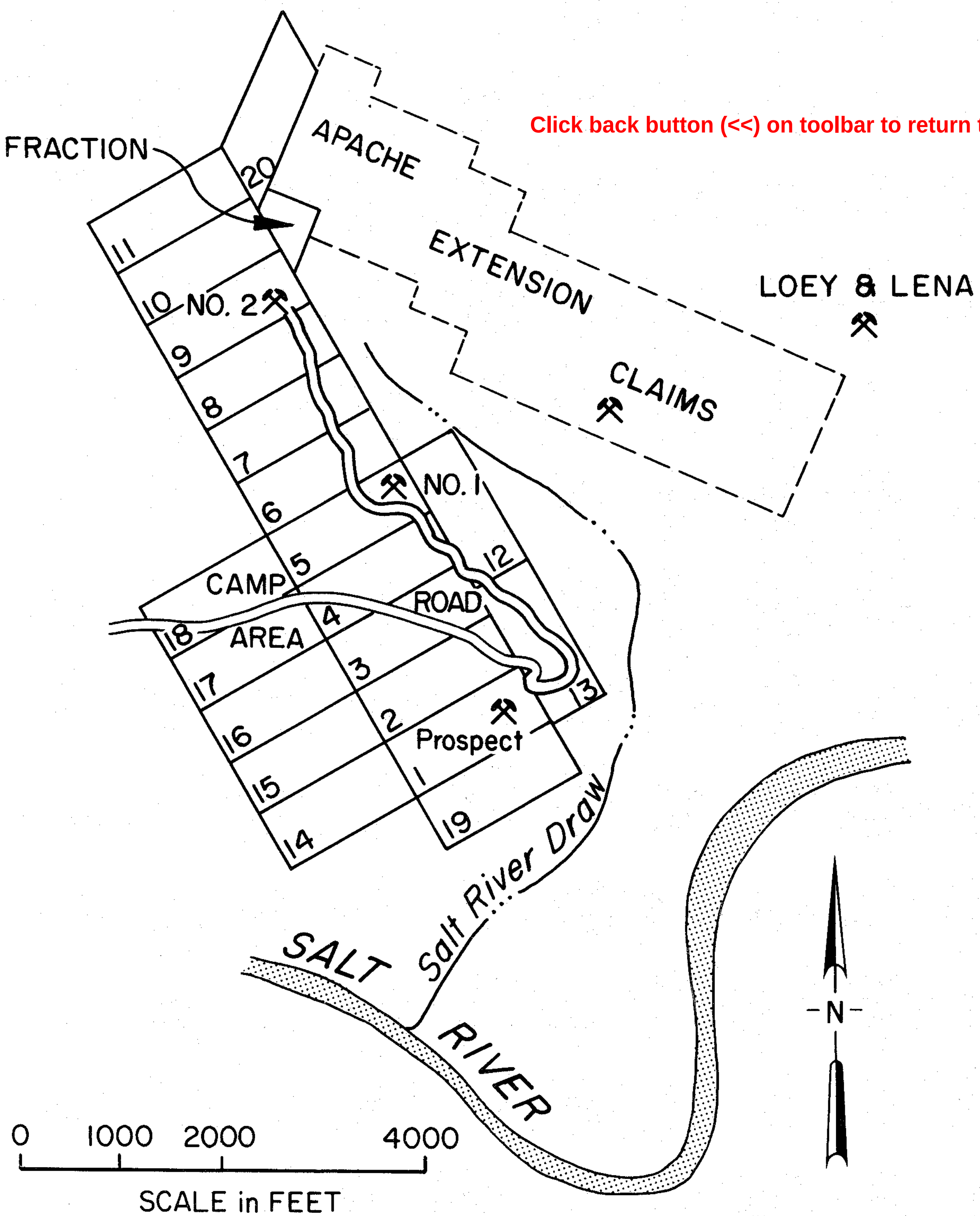

Figure 7. The Apache and Apache Extension asbestos properties, Fort Apache Indian Reservation (adapted from Stewart, 1955, p. 38).

Click back button (<<) on toolbar to return to text

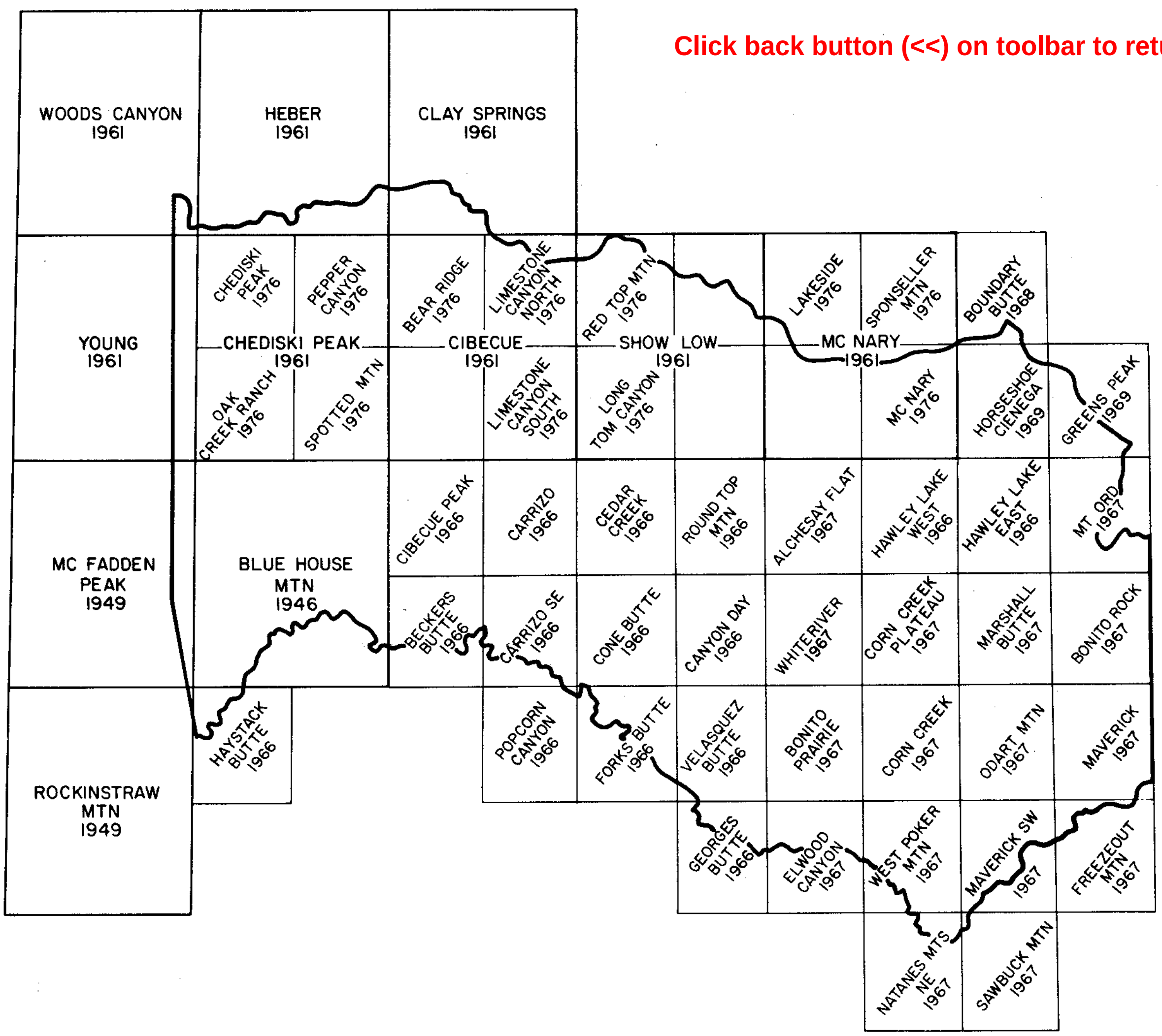

Figure 8. Index map of Fort Apache Indian Reservation showing the location of 7 1/2-minute and 15-minute quadrangle topographic maps.